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H. H. SWINNERTON

The Earth Beneath Us

The origin, age, and formation of the earth and the start of life upon it

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This Earth on which we live – whence did it come? How old is it? How were its rocks formed, its valuable minerals and precious stones found? How were its mountains uplifted and its subterranean passageways excavated? When did life appear upon it? How did flowers, animal pets, and man himself evolve? These and many other questions that are asked about the earth and its inhabitants are discussed in this fascinating book.

The answers, that scientific investigators and specialists in many different fields of study have given, are here explained in simple non-technical language. The results of their work, in their respective lines of enquiry, are brought together and interwoven in such a manner as to bring into prominence Nature's ways of working and the general processes by which, through the ages, she has been establishing and beautifying this world and has kept up an unbroken succession of tenants.

Professor Swinnerton presents a brilliant summary of geological and archaeological information in this absorbing story of our planet.

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THE EARTH BENEATH US

H. H. SWINNERTON

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The Earth Beneath Us

H. H. SWINNERTON

PENGUIN BOOKS

Penguin Books Ltd, Harmondsworth, Middlesex
AUSTRALIA: Penguin Books Pty Ltd, 762 Whitehorse Road,
Mitcham, Victoria

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First published by Frederick Muller 1955
Published in Pelican Books 1958

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Made and printed in Great Britain
by William Clowes and Sons, Limited, London and Beccles
Gravure plates by Harrison & Sons, Ltd.

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PREFACE

THE main centre of interest for the science of Geology is 'The Earth Beneath Us'. At its boundaries, however, this science merges into other branches of knowledge and consequently it feels the pulsations of thought moving in the minds of workers in other and diverse fields of enquiry. On this account the study of Geology has a peculiar educational and cultural value.

During the writing of this book I have felt deeply indebted to the staff of the Department of Geology at the University of Nottingham and especially to Professor W.D. Evans and Miss Irene Bruce for their unfailing courtesy and kindness in responding to my frequent demands upon their time and special knowledge. In a book that covers so wide a field mistakes can hardly be avoided, the responsibility for these lies solely with me.

In seeking for and securing illustrations I owe a large debt of gratitude to the following:

First and foremost to the Director of H.M. Geological Survey for fifteen geological photographs from their wonderful collection. The copyright of these is reserved by the Crown and they are reproduced here by the courteous permission of the Controller of H.M. Stationery Office.

My cordial thanks must also be recorded to: the *Yorkshire Post*, Leeds; the Mount Wilson and Palomar Observatories; the Council of the Geologists' Association with Professor H.H. Read; Professor W.D. Evans, Dr F.A. Henson, Dr T.W. Taylor, Mr R. Bentham, Mr F. Potts, Mr F.T. Baker, Mr W. Sutcliffe, and to Mr M.P. Brand.

H.H. SWINNERTON

Nottingham University
May 28th, 1954

Part One: The Origin of the Earth

I

ONE OF A FAMILY

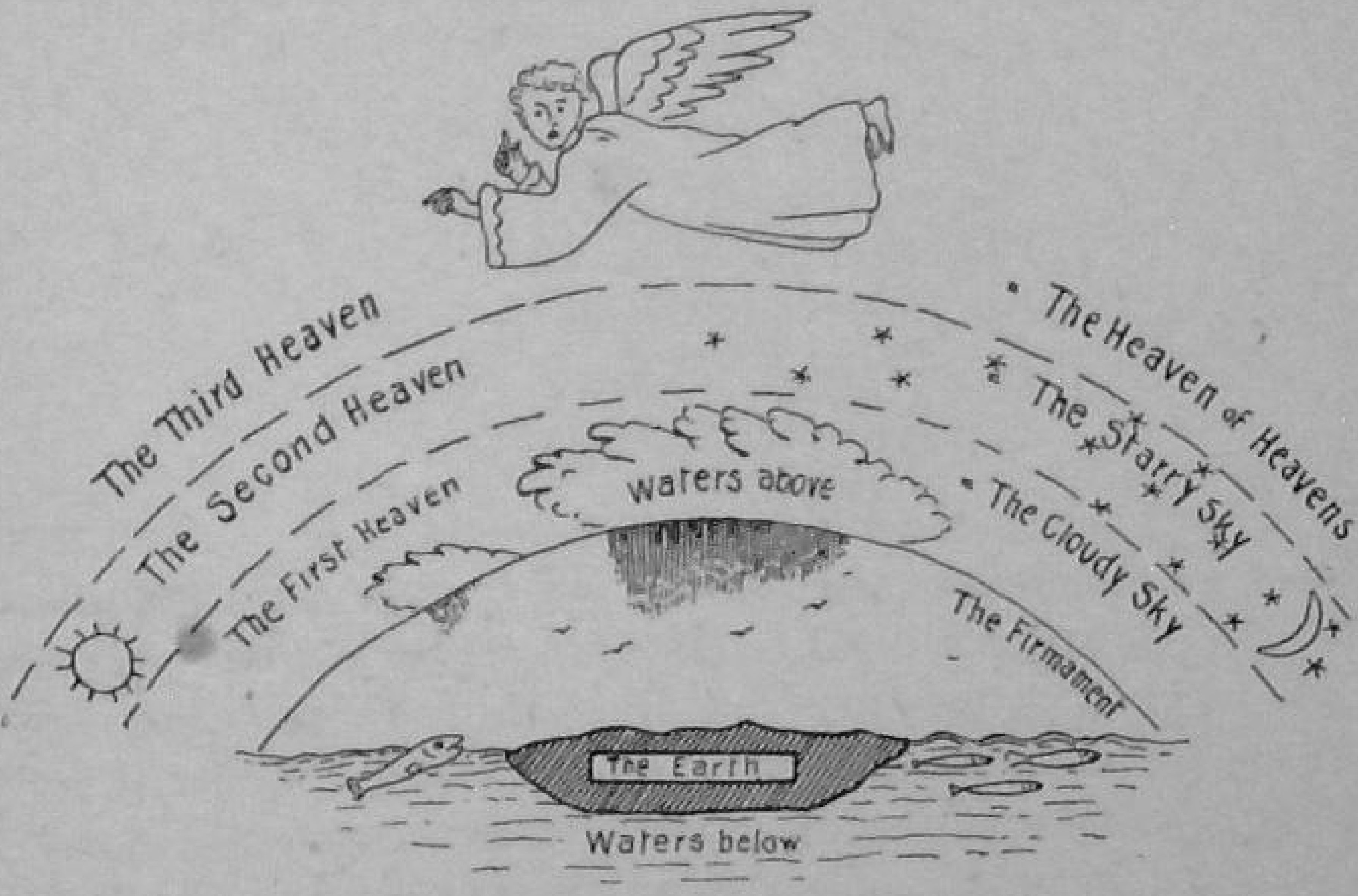

FIG. I. ANCIENT IDEAS OF NATURE

Diagram illustrating the ideas of the world and the universe which prevailed in ancient and medieval times

JOSEPH dreamed a dream. In it he saw the sun, moon, and the eleven stars come and do obeisance to him. His friends thought him conceited; but even they in daily life looked upon these heavenly bodies as their servants set in the skies to mark for them the passage of time, of day and night, to fix the dates of festivals and of changing seasons, to warm the soil and ripen their crops. They, in common with their fellows in ancient times, believed that the stars played an important part in the

lives of men and women. Even in these enlightened days people still talk about being 'born under a lucky star'.

Indeed the heavenly bodies played such an important part, real and imaginary, in man's daily life that the learned men of those times devoted their days and nights to studying the sky. They became familiar with the patterns made by the stars and devised picturesque names for the constellations, such as the Plough, Orion, Cassiopeia. They discovered that the sun and moon travelled across the sky along a definite path against the background of that pattern, threading their way through a series of constellations, called the zodiac, whose names are recorded in the familiar jingle:

The ram, the bull, the heavenly twins,
And next the crab the lion shines,
The virgin and the scales,
The scorpion, archer and he-goat,
The man that carries the water pot,
The fish with glittering tails.

They studied the phases of the moon and watched her wandering along the same path.

They discovered that there were five stars which did not keep a fixed place in the pattern as did all the other stars but wandered from one constellation to another in the zodiac. These they called *planets* or wanderers and gave them special names: Mercury, Venus, Mars, Jupiter, and Saturn. They drew complicated plans to show how all these bodies circled round this earth of ours.

During the six centuries which preceded the birth of Christ Greek philosophers made remarkable progress in these studies. They realized that when the moon was eclipsed it was merely hidden from view in the shadow cast by the earth. Because this shadow was round they concluded that the earth was round like a sphere. One of them, Eratosthenes by name, observed that the shadow cast upon the ground by an upright pillar at noon, when the sun was at its height, was longer at Alexandria, where he lived, than it was at Syene more than 500 miles farther south. With measurements, made on these shadows as a

basis, he estimated that the earth had a circumference of 31,250 miles. Considering the crudity of his apparatus this was reasonably near the true figure which is 24,902 miles. They discovered that the observed movements of the planets were much more easily understood if it were assumed that, together with the earth, they circulated round with the sun as the centre. Unfortunately Aristotle still held to the more ancient view that the earth was the centre round which the sun, moon, and planets moved. This view continued to be generally held until the sixteenth century when Copernicus, a Polish astronomer, showed by his calculations that the other Greek philosophers were right. An interesting confirmation of his view was produced by Galileo, an Italian astronomer who, having made for himself one of the newly invented telescopes, turned it to the sky in 1609 and saw Jupiter with a family of four moons circling round him.

From that time onwards every observation and calculation has furnished additional proof that Copernicus was right, that the earth is one of a family of planets revolving round the sun. Since his day three new planets have been discovered: Uranus in 1781, Neptune in 1846, and Pluto in 1930. Many facts have been established about each member of the family: size, weight, speed of rotation, distance from the sun, shape and size of orbit, and rate of travel round the sun. A few of these may be useful for our purpose and are noted below.

The sun has a diameter of 865,000 miles. It rotates on its axis once in 25 days. It is 333,400 times as massive as the earth, and its average density is 1·41 times that of water.

The diameter of the earth at the equator is 7927 miles and between the poles is 7900 miles. It completes one rotation on its axis in 23 hours 56 minutes. Its average density is 5·52 times that of water and is greater than that of any other large body in the solar system. Its average distance from the sun is 93,003,000 miles. It travels at a speed of 18½ miles per second, and makes a complete circuit of its orbit in 365¼ days.

The vast extent of the solar system is indicated by the fact that the average distance of Pluto from the sun is no less than

40 times that of the earth. Travelling at a speed of 3 miles per second it traverses its orbit once in 248 years.

At the other extreme from Pluto is Mercury, which is slightly more than one-third as far from the sun as the earth. It completes its journey round the sun in 88 days, and travels at the rate of 30 miles per second.

2

THE FAMILY PEDIGREE

THIS earth, this home of man, this family to which it belongs, how have they all come into being? For three centuries men have puzzled over this problem. They have made diverse guesses at an answer and tested them carefully by reference to known facts. As yet no unanimity has been reached. The conflict of ideas and hypotheses still goes on, and the most that can be done here is to trace the general course which it has followed without attempting to forecast new discoveries or ultimate conclusions.

The naturalist Buffon (1707–88) made one of the earliest guesses. He suggested that some other heavenly body, such as a comet, collided with the sun. He did not picture a head-on collision but a glancing blow which skimmed off part of the sun's surface and sent it flying off into space where it broke into fragments. These condensed and became planets rotating on their axes and rolling round the sun, all in the same direction.

The philosopher Kant (1724–1804) thought that the solar system might have originated in a diffuse nebula, a dimly luminous cloud of 'fire mist' like that revealed by the telescope in the constellation of Orion. By doing so he carried the imagination back to the primal substance of the universe. As we now know, each nebula is a local concentration of matter in its simplest form; of highly charged centres of energy called electrons, and of clusters of these regularly organized into groups called atoms. Such infinitesimally small centres of

energy are apparently widely distributed through infinite space. According to some research workers new electrons are being created all the time, infinitesimal foci of activity on the part of Ultimate Reality. Presumably in the nebulae new atoms are also being created, new groupings of electrons endowed with new properties by which scientists can identify them and give them names such as *hydrogen*, *helium*, and *oxygen*.

Kant pictured the mist of primal substance as gravitating towards the centre of the cloud, at first slowly and then more quickly. The pattern of this movement was similar to that of water in a wash-hand-bowl flowing towards the outlet. The path it followed started as a gentle curve which became increasingly spiral until it was almost circular near the centre. In this way the whole nebula with its dense centre, the future sun, began to rotate.

The French mathematician Laplace (1749–1848) carried the idea on from this stage. Having in mind the clear-cut and beautiful vision of Saturn and its rings he developed the idea along similar lines. He pictured the primeval sun, with its vast atmosphere of gases stretching beyond the limits of the known solar system, rotating around an axis. As cooling and condensation advanced, the nebula contracted and its speed of rotation increased. Consequently the great globe bulged more and more at the equator and flattened at the poles until it resembled a swollen disc rather than a sphere. Eventually the rate of travel at the rim became so great that this tended to fly off, like water from a bicycle wheel on a rainy afternoon. This tendency, however, was balanced by the gravitational pull towards the centre. The rim, like a man hesitating whether to go forward or turn back, remained stationary in a state of equilibrium. With the continued loss of heat and energy the rest of the disc continued to contract and shrunk away from the rim, which was thus left as a separate ring that went on rotating. At last this ring broke and collapsed to form a globe or planet. This process was repeated until the family of five then known planets was completed.

This 'Nebular Hypothesis' as set forth by Laplace seemed so complete and satisfying that it held the field for nearly a

century. Meanwhile astronomers improved their telescopes, invented new instruments, multiplied observations, calculated distances, and studied celestial mechanics. By the end of the nineteenth century they began to realize that this hypothesis by no means supplied a satisfactory explanation of many newly discovered facts and therefore did not provide a final solution of the problem. In any case, though many nebulae of suitable size were known none of them showed any indication of the type of ring formation which the hypothesis required.

At first sight the mechanics of the solar system seemed to give strong support to this hypothesis. As indicated above, the rate of rotation of the solar nebula increased as it shrunk and separated off the successive rings. Taking the planets in turn, from the outermost inwards, their speeds of travel expressed in miles per second are as follows: Pluto, 3; Neptune, 3⅓; Uranus, 4; Saturn, 6½; Jupiter, 8; Mars, 15; Earth, 18½; Venus, 22; Mercury 30. Could any set of facts be more convincing? Unfortunately the sun lets the argument down badly for at the rate of increase shown by these figures the speed of travel of the surface of the sun should be about 270 miles per second. If it were indeed spinning round at that rate, it should show a marked flattening at the poles and bulging at the equator. But every day we can see for ourselves that it is perfectly round. Evidently there was something amiss with the Laplacian hypothesis.

The same facts can be expressed more precisely in another way.

The figure arrived at by multiplying the mass of a moving body by its speed is called its 'momentum'. If this in turn is multiplied by its distance from the centre of the system the figure obtained is called the 'angular momentum' of the body. Owing to the high velocity of the planets and their great distance from the centre their angular momentum as a whole makes up no less than 98 per cent of the total angular momentum of the solar system, while that of the sun is only 2 per cent. No hypothesis can be regarded as satisfactory unless it accounts for this curious fact. The Laplacian hypothesis failed to do this so the problem which, for nearly a century, seemed

to be solved had now to be reconsidered. The guessing game started again, but now the guessers had a much larger body of known facts to guide them.

The game was reopened by Chamberlin and Moulton, two American scientists, the one a geologist the other a mathematician and astronomer. They were quickly followed by Jeans and Jeffreys in England. The line of attack they developed was fundamentally that suggested by Buffon a century and a half earlier, namely an encounter between the sun and another heavenly body. Instead of a flimsy comet a much more substantial star was brought into the picture, and the emphasis was shifted from a glancing blow to a near miss. As the star drew near to the sun the strength of its gravitational pull produced a tidal wave, like that produced by the attraction of the moon upon the waters of the ocean, only much larger. As the star passed its nearest point to the sun the crest of the wave was drawn out as a long stream of gas which became detached from the sun. While the star passed on its way the rest of the wave fell back into the sun, but the stream for a short time followed the star like a little dog chasing a motor-car. It was, however, soon left behind. Unlike the dog the long separated mass of gas broke into pieces which condensed and formed planets travelling at speeds which had been enhanced during the brief pursuit. Still held by the attraction of the sun, they entered upon their unending planetary journeyings.

Opinions differ widely as to the size and number of the pieces. At one extreme is the view put forward by Chamberlin and Moulton that the gases rapidly cooled and formed innumerable small and even minute solid bodies which circulated round the central sun like tiny planets or planetesimals. These were irregularly distributed, sometimes in clusters, elsewhere widely spaced. With the passage of time the clusters became more closely packed and formed small medium-sized planets which grew to their present size by drawing to themselves the other planetesimals. The last phases of this process may be seen presumably on clear, starry nights when showers of meteors illuminate the sky.

At the other extreme the view is very widely held that most

of these pieces were quite large and the same in number as the planets now seen. All were gaseous at the outset and, owing to differences in size, have cooled at different rates. One of the smaller pieces, the future earth, cooled more rapidly and condensed first to a liquid and then a solid state.

But while these 'tidal theories', based upon the idea of encounter of the sun with another body, gave an explanation for part of the greater angular momentum of the planets, they did not explain it all, for they left these bodies still too near to the sun. The known presence in the skies of many double stars suggested a possible way out of this difficulty by assuming that once upon a time the sun had a companion. It was further assumed that these two suns revolved around one another and were separated by a distance about the same as that of Jupiter or Saturn from the sun to-day. In this case it was suggested that it was the companion that experienced the actual encounter and suffered the loss of the gaseous mass which became planets. These bodies having originated in the companion were already placed at a suitable distance from the sun. So far so good, but the problem which now cropped up was how to get rid of the companion which is not to be seen anywhere in the solar family. It may be that the approaching star pulled it so far out of its old course that it broke away from the influence of the sun and went careering off into space, where it has since pursued a path of its own.

While all these guesses were being made and being tested by mathematical calculation the new study of radioactivity was making rapid progress and opened out to astronomers fresh lines of enquiry in seeking for a solution to the problems we are now discussing. A promising line of approach was suggested by the contemplation of those 'new' stars called novae, of which the Star of Bethlehem may have been an example. These were originally obscure or even quite unknown stars of a type which suddenly blaze forth with a brilliance far exceeding that of any other star in the firmament. After a brief period of outstanding glory they rapidly decline and at last sink into insignificance once more or even disappear completely from sight. In common with the sun they had for ages poured forth

energy in the form of heat and light which had been derived from internal radioactive processes involving the conversion of hydrogen into helium. When at last the store of hydrogen became exhausted the supply failed. The star now cooled and contracted. This resulted in great increase of pressure within the star and a corresponding rise of temperature amounting to many millions of degrees centigrade. Under these new conditions other and more complex atoms disrupted with a tumultuous release of energy. Like a gigantic atomic bomb, the star exploded and formed a vast, rapidly expanding, and highly luminous cloud which for a brief spell shone with extraordinary brilliance in the heavens.

This sequence of events was pictured by Lyttleton and Hoyle as taking place in the sun's giant companion. When the super-explosion took place there was a recoil of commensurate power which sent the companion flying away from the sun to pursue a lonely course through infinite space. However, as a kind of memento of the long companionship, a final puff from the explosion left behind enough gaseous substance within the gravitative influence of the sun to produce the planets. Whether or not this last guess brings us really any nearer to a final solution of the problem of the origin of the planets and of the earth is a matter for further enquiry.

Meanwhile a German worker has harked back to the original nebula as Laplace conceived it, that is to a flat disc-shaped mass of gaseous matter extending farther afield than the orbit of that last-discovered planet – Pluto, which is about 3670 millions of miles from the sun. This worker believes that minor vortices developed and rotated within this mighty rotating vortex of gases. While the nebula revolved round its central sun, each minor vortex that it contained became a separate ball of gas and ultimately condensed to form a planet. One of these became the earth. So this fascinating game goes on and provides incentives to pursue the enquiry yet farther along trails both old and new.

3

THE BIRTH AND CHILDHOOD OF THE EARTH

A HOLIDAY at the seaside, bathing and tasting the brine on our lips, lying on the warm sand waiting for the tide as it comes and goes, watching the waves rise into breakers, curl over and fall with a musical splash upon the shingle, all seems very remote from the problems concerning the birth and childhood of the world. Nevertheless it is just such experiences as these which underlie the long and studious efforts of scientific men to find the answers to the questions: When was the earth born? How old is the earth? What was it like when the earth was very young?

Sea-water tastes salty to us because it contains a little more than 2½ per cent of its own weight of salt. Drinking water does not taste salty, but if it contained no salt it would taste insipid. The quantity it contains is very minute as compared with that of sea-water. One of the early attempts at finding the age of the earth was based on the idea that every river in the world contributes a certain amount of salt to the sea yearly. The water it brings ultimately evaporates from the surface of the ocean, but the salt is left behind. It seems quite straightforward to conclude that by estimating the total amount of salt in the sea and dividing this by the total amount annually contributed by the rivers the answer would give the length of time which has elapsed since the oceans came into being. That would, of course, be a minimum for the age of the earth. Unfortunately this calculation is based on a number of uncertain estimates, and consequently the answers vary greatly from 80 million years given by the early calculators to 330 and even 1500 millions of years given by the later ones. Apart from all this uncertainty, there is another body of facts, usually overlooked. Judged by the richness and abundance of life in the sea, and by the vastly greater variety there than in the fresh waters and

on the land, it is safe to assume that the sea was the original home of living things. No doubt the salinity of the fluids of the body, even of land animals, is a reflection of that fact. The records of the rocks give support to this assumption that 500 million years ago, long before the land became inhabited, the seas teemed with life. This and other facts show that organisms lived and evolved in the sea for an equally long period before that. It seems, therefore, that the salinity of marine waters has been practically the same as it is to-day for at least 1000 million years. It seems probable, therefore, that the net contribution of salt made to the seas by rivers and other processes during that long period of time has been negligible. It should be noted, incidentally, that the existence of great salt deposits inland points to other processes which remove salt from the sea and tend to cancel out the riverine contributions.

When a wave breaks with a splash upon the beach the water flows back into the sea as a current moving under the next approaching wave. When the sea is rough the waves are much bigger and consequently this back-flowing current, or *undertow* as it is called, is correspondingly stronger. Indeed it is sometimes so strong that an unwary bather may be swept off his feet and sucked down, carried out into deeper water, and drowned. In like manner the sand is being continually carried out to sea away from the beach and spread out like a carpet upon the sea floor. As the months and years pass, sand and other sediments are piled up to a considerable thickness. Each layer of sediment represents the brief period of time during which it was being laid down. Ultimately these layers are converted into rock, often of vast thickness. With these facts in mind, estimates have been made of the total thickness of sedimentary rock that have been formed on the face of the earth and of the total time that would be required for their formation. Here again there are so many uncertainties at each stage of the calculations that no completely accurate answer can be expected. If one certainty does emerge from this accumulation of uncertainties, it is the deep impression of the vastness of geological time, of the time during which the processes have been at work upon the earth. Nevertheless, as will be seen

later, some very satisfactory and indeed precise answers have been arrived at by kindred means for the actual length of much shorter periods of time. We must now turn from the geological to the astronomical approach to the problem.

Once more we sit up from basking on the beach and watch the waves chasing one another towards us. As we do so we may notice that out yonder in the deeper water they appear as long low undulations of the surface. Careful investigation has shown that as a wave sweeps along the surface of the sea it does not disturb the water appreciably at a depth greater than its own length. Even in the most furious storm all is tranquil and peaceful down below. As the wave approaches the beach it enters water that is shallower than the length of the wave. The friction between the roots of the wave and the sea floor hinders the movement of the water with the result that the wave becomes shorter and higher. The movement of its crest is not impeded and so it carries on, curls over, and falls down, like a man stepping carelessly from a moving train on to the platform. His feet are held by friction with the ground, but his body continues to travel forward and so falls. The swilling of the water up the beach and back again as each wave breaks reproduces in miniature the incoming and outgoing of the tide which is in fact a long wave that goes sweeping along the coast.

As we recline upon the beach, basking peacefully in the sunshine, we are quite unconscious of the fact that the earth is rolling round and carrying us along at great speed. Meanwhile the gravitative attraction of the sun and moon pulls the surface of the sea up into a very extensive but not very high wave, the tide. This is usually spoken of as travelling across the oceans. In actual fact, however, it is being held in an almost stationary position while the ocean floor, rolling along with the rest of the world, from west to east, passes in under the wave and comes out on the other side. The off-shore shallows, backed by cliffs on the western side, are also carried in due time through the roots of this tidal wave. During their passage through they encounter friction with the water. This relatively stationary tidal wave thus acts like a gentle brake pressing upon the surface of the earth. It is believed that the friction thus caused

gradually slows down its rolling movement. Astronomers have compared records of the actual times at which eclipses have taken place in the past with the calculated times and have discovered that discrepancies between the two figures occur. An outstanding example which shows that slowing down has actually taken place during historic times is furnished by the record of an eclipse which was observed in Babylon in the year 721 B.C. This was found to differ from the calculated time by as much as 3½ hours.

With such facts as a starting-point careful investigations have been made into the effect of the braking action of the tides upon the rotation of the earth. It has been shown that the rate of this must have been slowing down steadily through the ages. To put it another way the length of our day, which is the time taken for a complete rotation, has gradually lengthened. Going into reverse and thinking backwards through time into the far-distant past it is evident that the speed of rotation of the earth would be seen to increase and the length of a day to shorten.

Calculations also show that the distance of the moon from the earth would diminish and its speed of revolution round the earth would increase. The general conclusion arrived at as the result of all this careful enquiry is that about 4000 million years ago the distance between these two bodies was only about 3000 miles and that the earth rotated and the moon completed its revolution once every four hours. The probable existence of this state of affairs is taken to indicate that the moon had only very recently separated off from the earth, which according to the astronomical point of view must then have been in a liquid state. Other much more complex calculations made in order to arrive at some idea of the date when the solar system came into being yield an answer closely approaching this same figure of 4000 million years. It seems, therefore, that the earth remained in a gaseous state for only a relatively short time and that the earth must have been born not very long before it gave birth to the moon 4000 millions of years ago.

Further cooling of the earth led to the formation of a rocky crust. Though much is already known about those areas of the

earth's surface where the oldest rocks are to be seen to-day no trace of the original crust has been found. That statement brings us to what is now generally agreed to be the most accurate and reliable means of arriving at the dates of the early events in the earth's history. It is based upon the fact that the complex atoms of some elements such as uranium undergo progressive disruption with the release of the very simple atom helium, accompanied by the discharge of radiant energy. The ultimate product of this disruption is the formation of a special kind of lead known as uranium lead. Now the rate at which all this takes place is accurately known. In order to discover the age of a sample of rock that contains uranium it is first necessary to find out by careful analysis the proportion of uranium still present to the lead which has been produced in this way. It then becomes possible to calculate the length of time that has elapsed while this process has been going on, and thus to get a correct estimate of the actual age of that piece of rock. In this way it has been shown that the age of one of the oldest rocks as yet known on the face of the earth, which outcrops in Manitoba, is 1700 millions of years. It therefore seems safe to say that it is at least 2000 million years ago since the surface of the earth consolidated. Taking all these considerations into account it is reasonable to conclude that this earth entered into a separate and independent existence from 3000 to 4000 millions of years ago and not earlier.

4

THE ANATOMY OF THE EARTH

We have seen earlier that there are two sharply contrasted theories of the birth of the world itself. According to one, which is in favour with some geologists, it grew from being a small body to its present size by the infalling of showers of 'meteors', or more precisely, planetesimals, and was solid from the outset. According to the other, which is perhaps more widely accepted, it started as a large gaseous globe. This

latter provides a convenient starting-point for picturing the conditions we should encounter if we could indeed make a journey to the centre of the earth. For a comparatively brief period the earth was first a gaseous and then a liquid globe. In both circumstances the heaviest material would sink to the centre and lightest rise towards the surface, thus giving a zonal structure to the interior of the earth crudely illustrated by the inside of an onion. At the same time, and throughout the long subsequent ages, the internal heat of the earth has been travelling outwards and becoming gradually dissipated from the surface. As the result of this loss the outermost zones cooled and eventually solidified. To what extent this change has extended inwards is one of the many problems that can only be solved by searching for further facts. In so far as these accord with this provisional reconstruction in the broad outline just given of the internal make-up of the earth, they will give support to the gaseous theory of the earth's origin. With this incentive in mind we may now set out in search of such geological facts.

A study of the rocks at the earth's surface reveals the existence of three main types of rock in the outer crust. These have been formed by processes which will be dealt with in detail at a later stage. Meanwhile it must suffice to name the types and indicate very briefly how they were formed. Granite and basalt are examples of the type known as *Igneous rocks*, so called because they were formed or at least appear to have been formed by crystallization and consolidation by the cooling of a hot liquid. Sandstone and clay are called *Sedimentary rocks* because they consist of small grains or dust-like particles derived from the destruction of the crystals in igneous rocks which have been carried by wind and running water and deposited as sediments in hollows on the land or in lakes and seas. Such rocks as gneiss and schist have about the same chemical composition as the other two, and have often been produced from these by being heated, impregnated with fluids, squeezed and churned until their appearance has been completely changed. They have in fact been metamorphosed and are called *Metamorphic rocks*. All the visible portions of the

earth's crust are made up of one or other of these three types of rock.

Starting, as we did, with a hot liquid earth it is natural to conclude that the original crust consisted of igneous rocks and that these are the oldest of all. It came, therefore, as a surprise to the early field geologists who were working over the most ancient stretches of the earth's surface, such as Finland and north-east Canada, to find everywhere that the igneous rocks appeared to have been injected into the other two and were, therefore, younger than these. Nevertheless it seemed evident that the material which made up these metamorphic and sedimentary rocks must ultimately have been derived from others which must have made up the primeval crust. It would have been a thrilling experience to have gone for a camping holiday upon a site of which one could write home saying: 'We are very much enjoying ourselves on this bit of the original crust of the earth.' It is to be feared, however, that no such bits remain; that in fact the rocks of that crust have all been shattered, turned into sedimentary rocks, churned into metamorphic rocks, or even transmogrified once more into so-called igneous rocks repeatedly.

Areas of these oldest rocks occupy the cores of all the continents and are spoken of as shields. The Canadian shield surrounds Hudson Bay. The Baltic shield underlies the Baltic and extends eastwards into Finland and northern Russia. Smaller shields occur in south India, in Central Africa, Siberia, Australia, and elsewhere. At their margins the larger shields pass below those vast areas of sedimentary rocks which make up so much of the surface of Europe and North America. They, therefore, constitute the foundations of the continents and are accordingly spoken of as the Fundamental or Basement complex, a very appropriate name. At that far-distant date when these oldest rocks were being formed the crust of the earth must still have been much warmer than it is now – perhaps it was actually hot.

Even to-day when a volcano bursts into activity it pours forth liquid rock or lava with a temperature of as much as 1200°C, sound evidence that the earth still has a heated interior.

The same fact is brought out in a less dramatic fashion by the mining industry, for it has been found that in making borings and sinking shafts there is a relatively steady increase of temperature downwards through the rocks amounting on the average to 1°C for every 60 or 70 feet. That is why coal-mining is an industry in which the management have little need to expend money on heating the places where the men work. On the contrary when the depth of the mines increases to 4000 feet or more the problem will be reversed, for it will then become necessary to provide cooling apparatus if mining is to be continued.

Assuming that this rise in temperature continues as the depth increases, it has been calculated that at the centre of the earth it will reach a level of between 2000° and 3000°C. At that rate it would be hot enough to melt the rocks at a depth of 22 miles. It does not, however, follow that they will be melted, for at such depths the increase of pressure is also an important factor. One of the facts that makes a great impression on the mind of a novice when he first goes down a mine is the way in which stout wooden props that are used to support the roof are shattered and iron ones crumpled by the pressure that the superincumbent rocks have exerted upon them. When, in the laboratory, a piece of rock is melted in the furnace it usually expands. But at great depths in the earth's crust the pressures are so great that this expansion cannot take place and consequently the rock cannot melt. It then becomes natural to ask, does this state of affairs prevail as far as the centre of the earth, or is there a depth at which the rise of temperature, as it were, catches up with the rise of pressure and so the centre is maintained in its original liquid state? In order to arrive at an answer to this question it is necessary to go in search of something that can penetrate the earth from pole to pole. That something has been found not in any wonderful piece of boring apparatus but in the vibrations that are set up whenever a great earthquake takes place.

The way in which these vibrations travel along this journey may be illustrated by two everyday observations. One is met with in a railway goods yard when shunting operations are

proceeding. The shunter unlinks the last truck of what may be a very long goods train. The engine then bumps the first truck. This bump is passed on from truck to truck. Though the train as a whole remains stationary, the blow is transmitted to the last truck which then runs off along the line with the impetus thus received. A wave that is transmitted in this way is described as a 'push-wave'. The other method of transmission is illustrated when two people are seen shaking a long carpet. If while one end of the carpet is held firmly the other end is shaken sharply up and down, the shake travels like a wave along the carpet. As it does so each bit of carpet vibrates up and down at right angles to the direction the shake is travelling. This is described as a shake wave. In the push wave the particles vibrate to and fro longitudinally, in the shake wave they vibrate transversely. The push wave is, therefore, a longitudinal wave and the shake wave is a transverse one. Both kinds of wave will travel through a solid, but only the longitudinal type will travel through a liquid. Keeping this distinction in mind we are now in a position to understand the behaviour of vibrations set up by earthquakes as they journey along their deep-down and invisible subterranean pathways.

When, as sometimes happens in the crust of the earth, the rocks are strained to breaking-point they snap suddenly and slip past one another. The rocks all round are severely jolted and powerful vibrations are set up which travel outwards from the centre of disturbance in all directions like waves spreading out on the surface of a pond when a stone has been thrown in. When a very severe earthquake takes place the whole earth is made to tremble with vibrations which travel through the interior as well as round the surface. In laboratories situated at many different places scattered over the globe delicate instruments are always ready to record any vibrations that reach them. The longitudinal waves travel more quickly than the transverse. When all the records made by these instruments are assembled many interesting facts emerge. Among these, two may be emphasized. Starting from the centre of disturbance it is found that the arrival of the transverse waves is felt at points round the surface of the earth up to a distance of

three-fifths of the earth's circumference from their starting-point at the earthquake centre. Beyond that no record is made. From this it is inferred that at a depth of about 2000 miles these vibrations come to a core through which they cannot travel because it is not solid but has the properties of a liquid. The part of the earth's surface where no records are made lies in fact within the shadow of this core. The longitudinal waves behave in a different fashion. After passing through the earth they too emerge at the surface up to the same distance from the earthquake centre. They also fail to emerge immediately

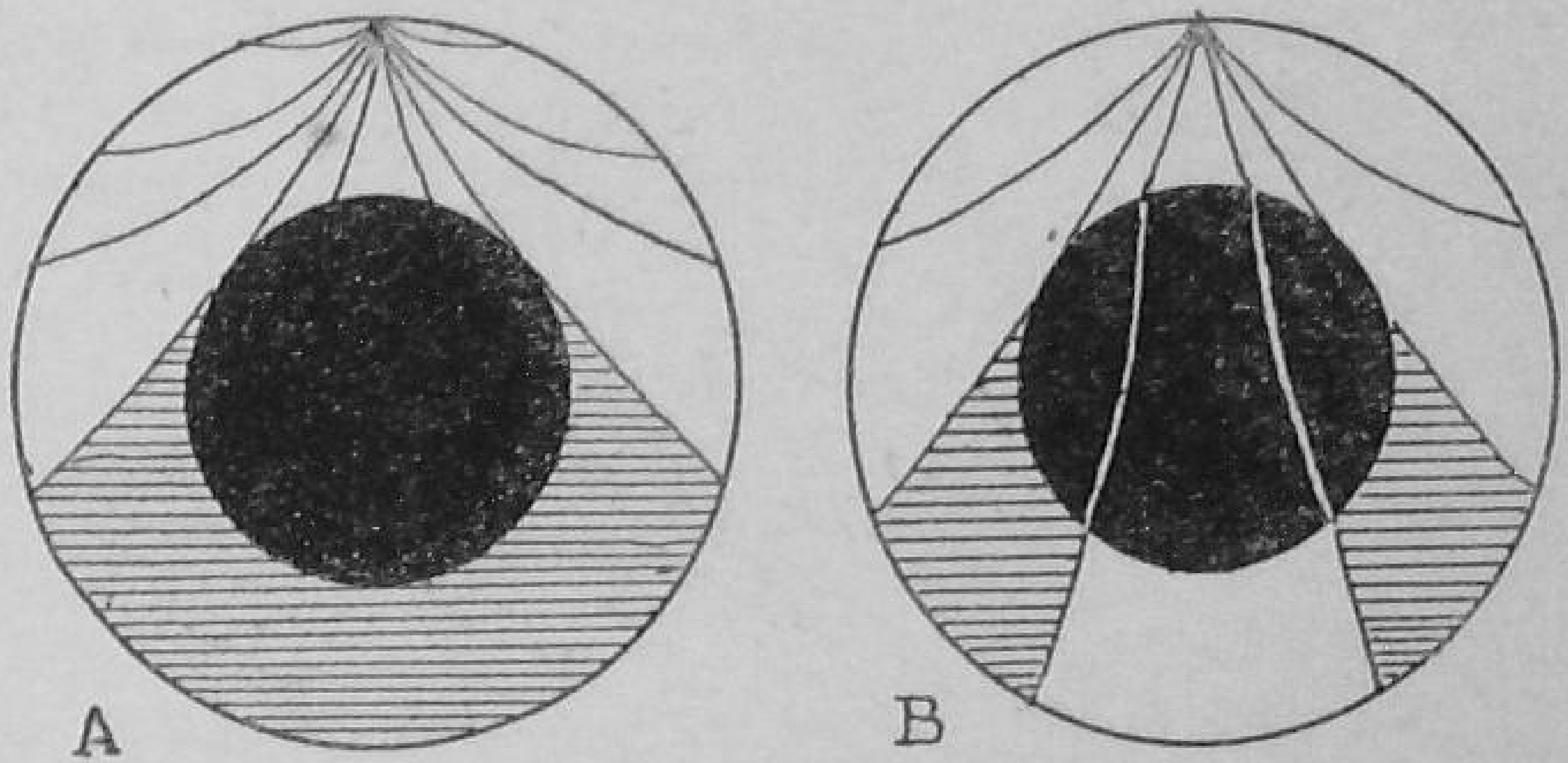

FIG. 2. THE INTERNAL ANATOMY OF THE EARTH

Diagram showing the paths followed by earthquake waves through the earth, transverse (A), longitudinal (B). The core of the earth is shown black, the shadows cast by it are shaded

beyond that. After a while, however, they put in their appearance once more about half-way to the antipodes. They, therefore, emerge over the central part of the shadow described above. Evidently these waves have passed through the core but in doing so have been deflected from their original path, and in consequence leave a ring-shaped shadow. The behaviour of longitudinal waves thus confirms the conclusion, suggested by that of the transverse waves, that there is a central core in the earth which, though it is under very great pressure, can be described as liquid.

The examination of these earthquake records brings to light

another highly interesting fact. It is that the vibrations travel through the deeply seated rocks more quickly than they do through those which lie nearer to the surface. From this it is inferred that the rocks deep down are denser and heavier than those above. All these facts combine to give us a picture of the interior of the earth as being made up of a liquid core surrounded by successive zones of rocks decreasing in density as they approach the surface.

Part Two: The Face of the Earth

5

ITS FACIAL FEATURES

CAST over most of her face the earth wears a thin but beautiful veil – the sea! Consequently only about 30 per cent of her face is seen in the form of land, which is broken up into large continents and innumerable islands. More than 80 per cent of the land is concentrated on that half of the globe which has its centre south of the English Channel in Brittany. This half is spoken of as the 'land hemisphere'. The other half, called the 'water hemisphere', contains less than 20 per cent of the land. It includes the whole of the Pacific Ocean and has its centre near to New Zealand.

Only that part of the face of the earth that is exposed as land is known in detail, for that part hidden by the sea is practically inaccessible. In ancient times mariners 'sounded' the depths of the shallow seas they navigated by means of a plumb-line. This consisted of a heavy weight at the end of a rope. Holding the rope in both hands the sailor stretched his arms to the full and thus measured off a length which was called a fathom. As soon as the weight touched the surface of the water he paid out the rope in lengths of a fathom, counting them up as he did so. As long as the weight was travelling freely the rope was taut, but when it touched the bottom he felt it slacken. In more recent times ships have ventured out on to the deeper seas and the number of ocean-going steamers became so great that governments began to fit out vessels specially equipped for exploring the oceans. In 1872 the British government led the way by sending out a research ship called the *Challenger*.

The principle of sounding by plumb-line was still followed

with greatly improved apparatus. The rope was replaced with steel wire which, because it was so thin, was not caught by currents and swept aside from the vertical, and yet it was strong enough to carry the greatly increased weight required for keeping the wire quite taut down into profound depths. The wire ran out from a drum and over a small wheel that actuated a dial and automatically recorded the depth. When the weight touched the bottom it was released and left behind, thus diminishing the load that had to be lifted back to the surface.

These research vessels worked along a network of lines, making soundings at intervals. In shallower seas operation was short and many soundings could be taken. But out in the open ocean one operation took two hours or more, on rare occasions five, and consequently fewer soundings were taken, at longer intervals. Of necessity, therefore, the knowledge gained was limited to widely scattered points. The intervals between these and the areas enclosed in the meshes of the network remained still unexplored. Thus only a general impression of the form of the sea floor was gained.

In recent years a new and much more rapid technique has been developed known as 'echo sounding'. The vessel is fitted with some device for making a noise in the water. This sound travels out in all directions through the water at a rate a little less than 5000 feet per second. When it strikes the bottom it is reflected and returns as an echo which is picked up as the vessel travels along. From the time which elapses between making the sound and receiving the echo it is easy to calculate the depth. The exploration of the earth's veiled face is, therefore, now proceeding much more rapidly and in greater detail.

One feature of outstanding importance for our immediate purpose emerges from all this work. It is that for a relatively short distance from the shore the sea is shallow and its floor slopes gently at a rate of only about one foot per mile until a depth of 600 feet is attained. Beyond that it sinks more rapidly to a depth of about 12,000 feet. More gentle slopes are then resumed. This zone with steeper incline is called the continental slope, and its base marks the real boundary between the continental masses and the ocean basins. These masses are platforms

raised about 12,000 feet above the floor of the basins. Each continental platform is made up of the land, the gently inclined shelf submerged beneath the shallow sea, and the steeper slope. The face of the earth then has two sets of major features; the very extensive ocean basins, and the less extensive continental platforms. The total volume of the continental platforms is relatively so small that if they were bull-dozed away and pushed into the ocean basins until the face of the earth were featureless the seas would cover the whole to a depth of several thousand feet. Notwithstanding all this, throughout geological time there have always been continents

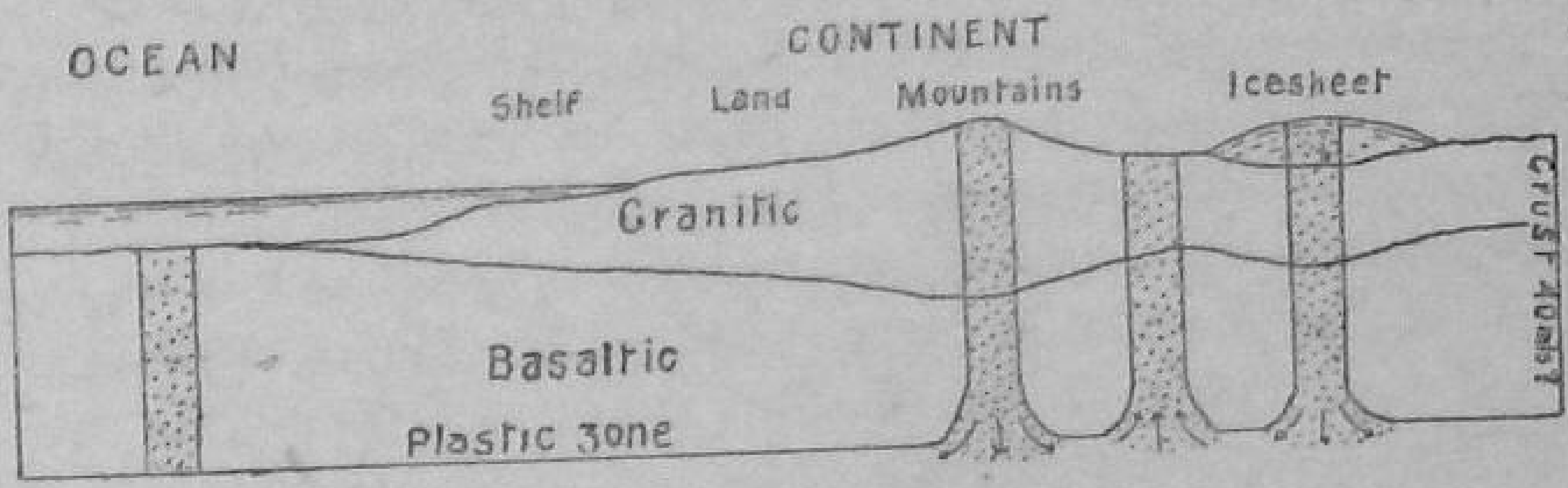

FIG. 3. THE CONSTITUTION OF THE EARTH'S CRUST

Diagram showing the general constitution of the earth's crust under ocean and continent. The dotted areas show columns of the crust in, or approaching isostatic balance

with land surfaces standing up above the ocean basins. When we stop to ponder on this fact, we begin to wonder why it should be so.

In searching for an answer to this question other facts begin to emerge which make the problem still more puzzling. For example, at the topmost point of Snowdon, the highest mountain in England and Wales, the rocks contain the fossilized remains of animals that lived in the sea when, ages ago, those rocks were being formed. Evidently these fossils and the rocks in which they have slumbered so long have been uplifted more than 3500 feet above their original level on the sea floor. Meeting with such facts is a common everyday experience in the life of a field geologist. Consider another example. Under the great Plains of North America and situated a thousand

miles away from the sea, at altitudes of 3000 and 4000 feet, rocks are found which also contain numerous fossil remains of marine animals; including the giant marine reptile *Mosasaurus* that lived millions of years ago when those rocks were also being formed on the floor of the sea. At the other extreme, borings that have been put down at Cape Hatteras on the east coast reveal the presence of rocks formed in the same way and at the same time down to a depth of 9840 feet below sea-level. Evidently since the days of *Mosasaurus* some parts of North America have been lifted high above sea-level, others have sunk thousands of feet below it.

Similar movements are still going on in many different parts of the world, not dramatically, but quietly and unobtrusively. For example, in Great Britain, which for some is a symbol of stability, on the east coast of Lincolnshire, north of Skegness, there was in the third century a Roman station at Ingoldmells. To-day the site of that station is completely covered by the sea every high spring tide to a depth of 10 feet. Evidently that part of the country has gone down at least that number of feet, probably more, during the last fifteen centuries.

Along the east coast of Scotland ancient sea beaches occur in positions 25 and 100 feet above the present sea-level. This fact, taken in conjunction with the situation of the Roman station on the Lincolnshire coast, shows that movements of sinking and uprising have been going on slowly even in comparatively recent times. Consider another example, this time from the heart of the North American continent, in the region of the Great Lakes. The ancient shore lines of Lake Michigan are horizontal at its southern end. When, however, the most extensive of these shore lines is followed northwards it shows a gradual tilt upwards. At first the rate of tilting is only one foot per mile, but it increases steadily until it is four feet per mile. Evidently the countryside around the north end of that lake has also undergone steady uplift for a long time.

As already seen, the continental platforms stand up almost like giant bastions above the floor of the oceans. We speak of them as *terra firma*, and think of them as quite rigid. Indeed, when we handle quite large chunks of rock, we feel justified in

speaking thus. We say the same also about small pieces of iron for they too feel quite rigid. Nevertheless we know that a long bar of iron, having the same thickness, sags or bends under its own weight. The facts enumerated earlier show that the large areas of rock which make up the continents are just as flexible.

We see then that the surface of the land is rising here and sinking there. This carries with it the implication that the rocks which immediately underlie it rest upon other rocks which are sufficiently plastic to be squeezed out from beneath sinking areas into and under rising areas. If we could handle a piece of that rock we should, no doubt, say that it was just as rigid as any other rock. But, at a depth of say 20 miles, it is under the very great pressure of the rocks above. Moreover its temperature must be much higher than it would be at the surface. Now a block of butter weighing only a pound is rigid enough to stand four square in the pantry; but we can easily imagine that, in a block weighing a ton, the base would become plastic and spread under the pressure of the rest of the butter. Half crowns and dollars were at first merely flat featureless discs of metal, but under great pressure they became plastic and took the shape of the die that was pressed upon them. It is not unfair to assume, therefore, that rocks subjected to such great pressures likewise become plastic.

It so happens, however, that geological processes working on the surface of the earth are constantly changing those deep-seated pressures. Thus, for example, wherever there is a great river system, like that of the Mississippi, large quantities of soil and gravel are being removed from considerable areas of the land surface and are being dumped at the mouth of the river in the form of a delta. It is not surprising, therefore, that the area where the delta is being built up is sinking slowly all the time. This movement is, of course, not evident to the eye of a casual observer because the river goes on building up the ground level by spreading more sediments on the surface as fast as it sinks. Deep borings, however, prove the presence of an accumulated thickness of hundreds or even a thousand feet or more of sediments in such deltas. Again, as will be seen in a later chapter, during the period popularly known as the Ice

Age, large masses of ice accumulated over North-west Europe and over Canada and adjoining portions of the United States. Under the pressure of these great loads regions centring around the Baltic Sea and the Hudson Bay sank considerably, but the regions beyond rose. Those great loads of ice eventually melted away. Slowly, but surely, the sunken areas have since then been rising and the uplifted areas have been sinking. These facts prove that this process of recovery has not yet been completed.

It seems as through the rocks which make up the continental platforms can be pictured as being arranged in tall columns standing side by side, all resting at their bases on a plastic zone somewhere about 35 miles below the surface. As long as these columns are equal in weight they balance one another, and are said to be in a state of isostatic equilibrium. If now the weights are changed, as in the examples described above, by the shifting of sediments or by the accumulation and melting of ice, this state of equilibrium is upset. The plastic subterranean material moves slowly from under the heavier column and pushes the lighter one up until the balance is restored. When this happens then isostatic recovery is complete.

If all the large features on the face of the earth tend to become isostatically balanced why, then, do the continental platforms remain standing up and the ocean basins stay down? Measurement of the strength of gravitation along oceanic margins suggests that the columns which make up the ocean floor consist of heavier rocks than those which underlie the continents. A fascinating stream of light is also thrown upon this problem by the study of earthquake records. We have seen how these show that the rocks deep down in the earth are denser than those found at the surface. By surface is meant the rocks which make up the continents, for these are practically the only ones upon which the geologist can lay his hands. Though sedimentary rocks cover much of the surface they form only a very thin veneer. The mass of the continental platforms is made up of rocks which, like granite, have a density of 2·7 times that of water. Earthquake records indicate that these rocks rest upon a foundation of heavier material with a density of 3·0 which is

generally assumed to be like basalt in composition. They also indicate that as the margin of the continental material extends outwards under the sea it diminishes in thickness and in some parts possibly disappears. Over great areas the ocean floor is closely underlain by this denser rock. A column of rock under a certain area of the continent is isostatically balanced by a column of equal extent under the ocean floor. It stands higher because it consists of a larger proportion of lighter rocks than does the column under the ocean. For this reason many think that continents have always been continents, and ocean basins always ocean basins.

Though rocks of about the same density as granite make up the mass of the continents, considerable areas of the land are covered with basalt, which was poured out as lava welling up from profound depths. This fact tends to confirm the view expressed earlier that the continents are like gigantic rafts of granite with their deep-seated portions sunken into basalt which becomes plastic under this great load. If the waters of the arctic seas were plastic and not liquid it would be legitimate, according to this view, to compare the continental platforms with those parts of the icebergs which are seen standing up above the sea, and the basalt with the water.

Chemical analysis shows that granite and basalt are alike in that both contain silicon; but they differ in that the former contains a moderate amount of aluminium, while the latter contains a similar amount of magnesium. By running together the initial letters of the names of these constituents the terms *sial* and *sima* have been devised for the lighter and heavier zones of the earth's crust respectively. It may be presumed that when the liquid earth cooled still further the lighter sialic material formed, for a short time, a complete covering over the whole earth. Just how this came to be broken up and clotted together in those masses called continents is still a subject for much discussion. One suggestion is that the still liquid sima, like soup boiling gently in a saucepan, was circulating up and down in convection currents. When the ascending currents came near the surface they divided and pulled the scum-like sial asunder. The pieces then drifted along until the currents

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It seems as through the rocks which make up the continental platforms can be pictured as being arranged in tall columns standing side by side, all resting at their bases on a plastic zone somewhere about 35 miles below the surface. As long as these columns are equal in weight they balance one another, and are said to be in a state of isostatic equilibrium. If now the weights are changed, as in the examples described above, by the shifting of sediments or by the accumulation and melting of ice, this state of equilibrium is upset. The plastic subterranean material moves slowly from under the heavier column and pushes the lighter one up until the balance is restored. When this happens then isostatic recovery is complete.

If all the large features on the face of the earth tend to become isostatically balanced why, then, do the continental platforms remain standing up and the ocean basins stay down? Measurement of the strength of gravitation along oceanic margins suggests that the columns which make up the ocean floor consist of heavier rocks than those which underlie the continents. A fascinating stream of light is also thrown upon this problem by the study of earthquake records. We have seen how these show that the rocks deep down in the earth are denser than those found at the surface. By surface is meant the rocks which make up the continents, for these are practically the only ones upon which the geologist can lay his hands. Though sedimentary rocks cover much of the surface they form only a very thin veneer. The mass of the continental platforms is made up of rocks which, like granite, have a density of 2·7 times that of water. Earthquake records indicate that these rocks rest upon a foundation of heavier material with a density of 3·0 which is

generally assumed to be like basalt in composition. They also indicate that as the margin of the continental material extends outwards under the sea it diminishes in thickness and in some parts possibly disappears. Over great areas the ocean floor is closely underlain by this denser rock. A column of rock under a certain area of the continent is isostatically balanced by a column of equal extent under the ocean floor. It stands higher because it consists of a larger proportion of lighter rocks than does the column under the ocean. For this reason many think that continents have always been continents, and ocean basins always ocean basins.

Though rocks of about the same density as granite make up the mass of the continents, considerable areas of the land are covered with basalt, which was poured out as lava welling up from profound depths. This fact tends to confirm the view expressed earlier that the continents are like gigantic rafts of granite with their deep-seated portions sunken into basalt which becomes plastic under this great load. If the waters of the arctic seas were plastic and not liquid it would be legitimate, according to this view, to compare the continental platforms with those parts of the icebergs which are seen standing up above the sea, and the basalt with the water.

Chemical analysis shows that granite and basalt are alike in that both contain silicon; but they differ in that the former contains a moderate amount of aluminium, while the latter contains a similar amount of magnesium. By running together the initial letters of the names of these constituents the terms *sial* and *sima* have been devised for the lighter and heavier zones of the earth's crust respectively. It may be presumed that when the liquid earth cooled still further the lighter sialic material formed, for a short time, a complete covering over the whole earth. Just how this came to be broken up and clotted together in those masses called continents is still a subject for much discussion. One suggestion is that the still liquid sima, like soup boiling gently in a saucepan, was circulating up and down in convection currents. When the ascending currents came near the surface they divided and pulled the scum-like sial asunder. The pieces then drifted along until the currents

began to descend. Here the sial fragments were packed together into continental masses.

In due time the sial clots and the underlying sima consolidated. Eventually they cooled sufficiently for the water, which fell as rain, to flow over the surface as rivers and streams and, filling the hollows of the earth's surface, gave birth to the oceans. That was the beginning of geological time which is estimated to have been between 2000 and 3000 million years ago.

6

TOUCHING UP THE FEATURES

GRANITE, in ordinary conversation among the laity, symbolizes hardness of heart, and strength of will, for in buildings where it has been used it resists successfully the action o agencies that would remove its polish, and destroy its surface; while all other stones perish and need to be replaced. But while human life is short, nature's time is unlimited and in the end she reduces even granite to sand and powder. She does it with gentle influences such as changing temperature and percolating water. Her ability to do this is due to the structure of granite. Even a casual look at its polished surface shows that it is made up of what looks like bits and pieces. Some of these are transparent like glass, and are called *quartz*; others are opaque and coloured a dirty white or pink, these are *felspar*. These two minerals make up most of the rock. Other minerals, such as *mica*, are also present but in much smaller quantity.

The daily change of temperature, from the coolness at sunrise to the warmth of midday, is a familiar and pleasing experience in temperate zones; but in tropical and polar latitudes the change may amount to 80°F or even 100°F. The experience of such extremes is far from pleasant both for human beings and for the quartz and felspar in granite. Exposed to the sunshine at midday the granite becomes very hot, and the bits and pieces of minerals expand and wriggle for room against one another.

Their hold upon one another is loosened. At night the heat radiates away from the surface of the rock, the mineral fragments cool, shrink, crack, and break loose from one another. The constant repetition of this struggle eventually shatters the surface of the rock, and the pieces fall away, leaving a fresh surface exposed to the same destructive influences. Meanwhile the fallen fragments are still further shattered and reduced to powder.

In mild and moist climates rain and air penetrate the substance of the felspars, dissolving part and changing the rest chemically into a white powder called kaolin or china clay. In winter the water freezes, expands, and shatters the quartz and undecomposed felspar. The dust and grains may remain and form soil; or they may be removed by rain and wind, thus exposing the deeper layers of rock to further attack.

In some regions like Central Africa, where there are extensive areas of comparatively level ground, the pulverized waste from the destruction of the rocks remains resting on the surface and forms rich fertile soil that becomes covered with vegetation. When this dies and rots, the acids produced mingle with the rain as it soaks down through the soil and continues its destructive action on the rocks below. In this way these may be disintegrated still further to depths of 100 feet or more. It is not surprising that in some areas stone for building purposes is not easily obtainable.

More usually, however, in all parts of the world the surface of the ground slopes gently or steeply. As rain-water flows down and washes over the ground it swills away the loose soils into the runnels. From thence it is carried down by streams and rivers to the sea. One result of this is that in all river basins the general level of the ground is being lowered; slowly here, more quickly there, but at a maximum rate of rapidity along the courses of the rivers themselves. Here the force of the current rolls the pebbles and boulders along in an unending procession towards the sea, grinding the floor of each channel more and more deeply into the rocks beneath. Just as an amateur, sawing a baulk of wood, sometimes eases his labours by chipping the wood away on either side of the cut, so rain and

frost loosen and break down the sides of the deepening channel; and what might have become a narrow, gloomy gorge is widened out into a sunlit valley, with soil-covered slopes for sides. Thus, throughout the landscape, thousands of streams initiate the formation of thousands of valleys. The ground near to and between the sources of the streams undergoes this process of 'aerial erosion' very slowly. It is, therefore, left still standing up as hills and fragmentary plateaux between the valleys. From this it may be observed that the streams were there before the hills were formed. It is the streams and not the hills that are everlasting. The poet Tennyson seems to have caught a glimpse of the idea when he wrote concerning the brook:

I chatter, chatter, as I flow
To join the brimming river,
For men may come, and men may go,
But I go on for ever.

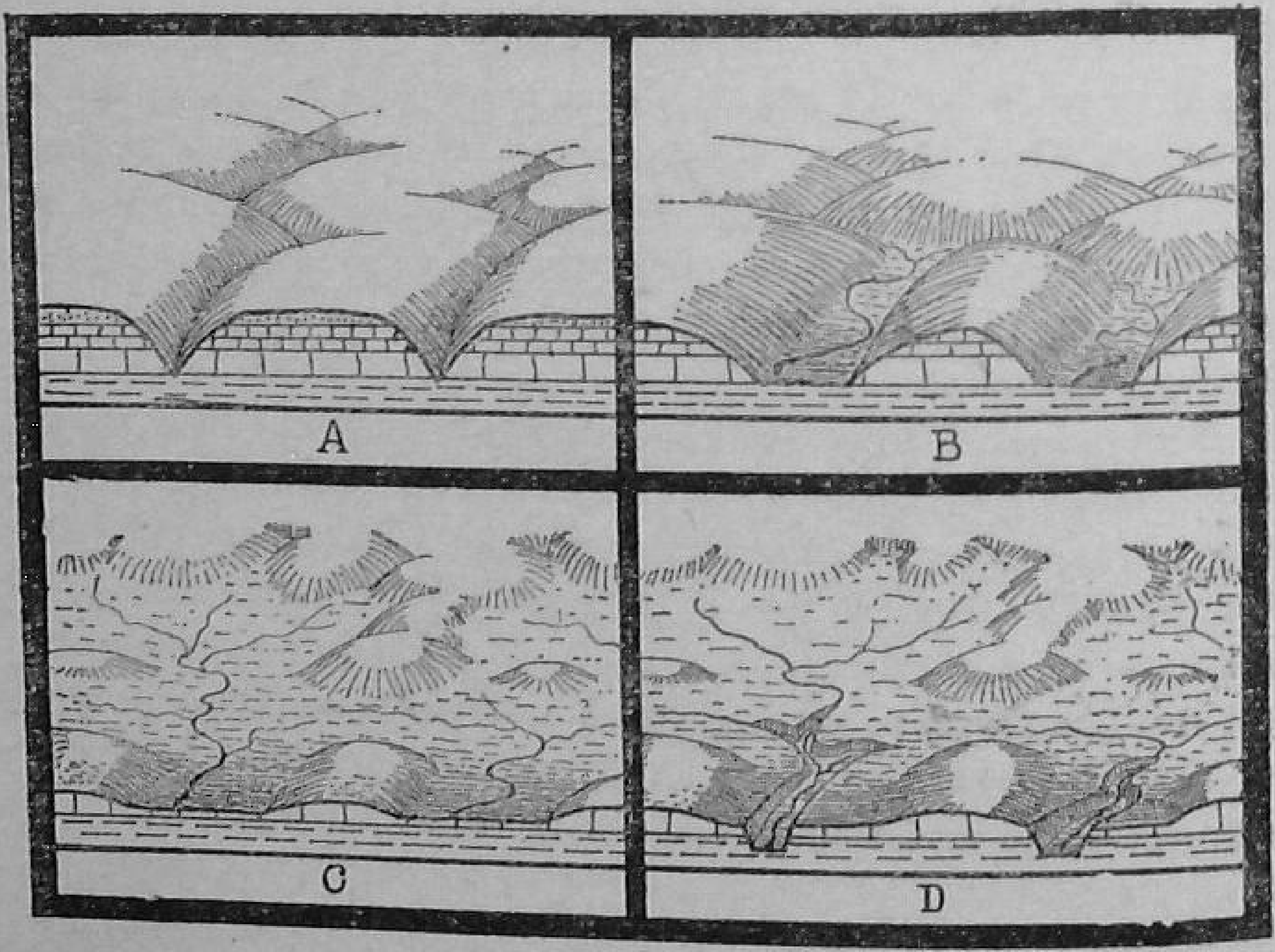

FIG. 4. PHASES IN A CYCLE OF PENEPLANATION

A, early; B, middle; C, late but not quite complete; D, uplift followed by rejuvenation of the rivers starts a fresh cycle

In due time, however, even the hills may be laid low and the landscape as a whole reduced almost to a plain, a so-called *peneplain*.

While all this goes on, the edge of the land is being steadily nibbled at by the sea. The waves, armed with shingle, pound the beaches and batter at the bases of the cliffs, wearing away the one, undermining the other until it falls and leaves a fresh cliff base to be attacked. Along the coastline, hill country and lowland alike are being planed down to one common level, the wave-cut platform or plane of marine erosion.

These same processes have been active down through the ages and worked, no doubt, upon that first landscape when the continental masses were born at the beginning of geological time.

When a wave breaks and swills up a beach its water runs back, plunges underneath the next oncoming wave, and, continuing as the undertow, lays hold of the fine gravel, sand, and mud, brought off the land by rivers or pounded off the beaches, and carries them out to sea. There it spreads them over the floor, depositing first the gravel, then the sand in the shallow water, and lastly the mud in the deeper water even as far out as the continental slope.

After a long time the sea floor may rise above sea-level with its carpets of sediments now, to a large extent, consolidating into rock. Thus exposed the erstwhile sea floor becomes a coastal plain, bounded along its inland margin by the original sea cliffs. The latter are then speedily worn by the various atmospheric agencies and are rounded off into hills.

7

PLAINS AND MOUNTAINS

JUST as sawing and planing wood reveal its grain or structure, so the excavation of gorges and valleys, the washing away of the soil from off a landscape, the cutting of cliffs along the coast, bring to light the arrangement of the sedimentary rocks that cover so much of the land like a thin veneer. Over great

areas, as for example in the broad expanses of Russia, and parts of the Great Plains of North America, the rock layers are flat and may be either horizontal or gently dipping. South of the plains of Central Europe and Russia come the Alps, the Carpathians, and the Caucasus Mountains. West of the Great Plains come the Rockies and the Sierras. In such mountain regions, along the sides of the valleys and the flanks of the peaks, the layers of rock are often seen to be folded and frilled intensely. Sometimes they have been sheared across and gigantic slices have been thrust out of place to the extent of 5, 10, or even 15 miles. Slice after slice has sometimes been made and these pushed one upon another, arranged like bread and butter neatly placed out on a plate for tea. The contemplation of the simple structure of the plains and complex folding in the mountains produces in the mind greatly contrasted impressions of nature in placid or in restless mood.

Everywhere the thin veneer of sedimentary rocks lies upon that foundation of metamorphic and igneous rocks already referred to as the Basement or Fundamental complex. In the plains, though hidden from view, its presence has been proved by borings. In the mountains also portions are exposed which have been pushed up from the depths. The examination of earthquake records has led some to estimate that these foundation rocks, together with the remainder of the sial, extend down to depths that vary greatly in different parts of the land hemisphere, but attain a maximum of about 50 miles in the heart of the great land masses, from thence it thins down to a minimum along the margins and under the oceans. In the opinion of some it is absent over considerable areas of the oceans, especially in the Pacific. Where that is the case the floor consists of sima. Others, basing their views almost entirely upon purely geological observations, consider that the maximum estimate given above is much too small and that the lighter crustal material extends quite probably across the ocean basins.

These extensive cakes of sial, called continental masses, are in reality very thin in proportion to their breadth and length. They, therefore, rest like giant flexible rafts upon a plastic sea

of slightly denser sima. For unknown reasons, broad, gentle undulations travel across them. The troughs of these may descend below sea-level and, while submerged, become covered with sheets of sediments. Eventually the troughs rise and become land covered by a new suite of rocks. Meanwhile the crests are eroded and worn down and may in turn be submerged.

Such movements have taken place repeatedly at irregular intervals through the ages.

As one of these broad troughs rises slowly, successive layers of new rocks are exposed as land, and their margins form parallel belts of country spoken of collectively as 'a belted coastal plain'. As the sea retires from this new land the rivers flowing down to it lengthen out. Smaller streams join the larger as tributaries. The drainage systems of the Mississippi and the Nile, the Don and Volga have been developing in this way for many ages.

Throughout the very long periods, during which those plains were being built up over large areas, there existed wide strips of the earth's crust, known as *geosynclines*, which often lay across the continental masses and remained submerged. Into these long, relatively narrow seas sediments were poured age after age. For reasons not yet fully understood, the floor of the geosyncline continued to sag and consequently the sediments accumulated to much greater thicknesses than they did elsewhere. The sinking did not, however, go on indefinitely. Gradually new forces came into action which buckled up the floor and gave rise to islands in this sea. Between these, sedimentation went on as before. Slowly, but surely, the forces gained in strength and the folds tended to rise higher, but instead of doing so fell over to one side. Other folds did the same and falling upon the earlier ones were subsequently pushed across and even beyond them. Often the rocks in the underside of the overfolds snapped, as though sliced through by a knife and the folds continued to slide forwards on the sliced surface ten or fifteen miles. Thus as mighty folds were piled one upon another, like Pelion on Ossa, great mountain ranges rose into being in the place where, for long ages, a sea

had rolled. Sometimes another and similar range of mountains arose alongside the first. In this, however, the folds fell and the thrusts moved in the opposite direction.

That, in brief outline, is the general story of those great ranges which stretch across the Old World from Spain, through the Alps and the Himalayas to the East Indies and again in the

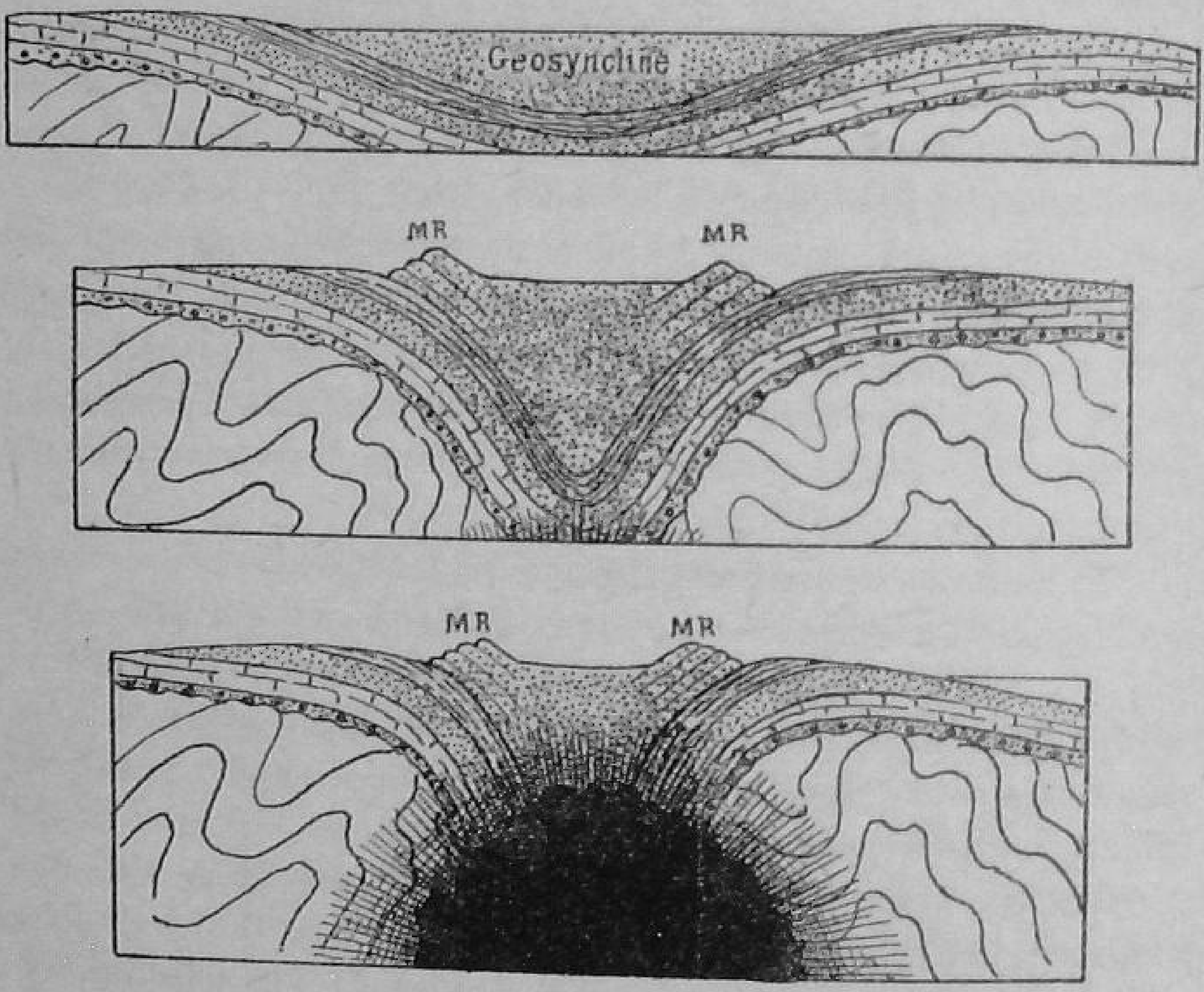

FIG. 5. GEOSYNCLINES AND MOUNTAIN BUILDING

Diagram illustrating the origin of a mountain system from a geosyncline, accompanied by changes in the deeply seated rocks. Black = a granite magna; shading = the zone of penetration by mineralizing fluids into other rock; M.R. = Mountain Range

New World from Alaska through the Rockies and the Andes to Cape Horn.

In some sections of these great mountain systems the two ranges are separated by spacious saucer-like hollows, called median basins, which may be traversed by minor folded mountains. The median basins vary greatly in altitude. Some are lofty plateaux, as in Persia and Tibet, others are low-lying

plains, as in Austria and Hungary; others again are submerged in the sea as is the case of the Tyrrhenian deep at the western end of the Mediterranean. Elsewhere along these systems the median basins are absent and the two ranges are crushed against one another as 'knots', like the Alps and Hindu Kush, where the mountain masses attain their most impressive developments.

In course of time the mountain-building processes slowed down and ceased. At the same time destructive processes began to come into action. Here and there small sections of the ranges foundered and left gaps, as for example in the south of France at the Gulf of Lyons or in the Aegean Sea. Thus were created gateways through the mountain barriers which to-day are used for the movements of mankind.

Such founderings were but passing incidents in the lifetime of mountain chains. On the other hand the work of rain and frost, rivers and glaciers, went on unceasingly for ages, reducing the rocks of the mountains to gravel, sand, and dust. These were transported to the lowlands and thence to the seas until at last only the stumps or roots of the ranges remained.

That mighty sequence of sedimentation, mountain building, and destruction has been oft-times repeated by nature during the lifetime of the world. The older the sequence the longer have the destructive phases been in action and the more deeply exposed have the roots of the mountains become. In various parts of the world, ranges of different ages are at different stages of destruction and can be examined. With the knowledge thus gained it has become possible to construct a composite picture of the structure from the topmost summits down to the deeply seated roots. The accompanying diagrams give the main features of that picture and illustrate the stages by which it was built up from the geosyncline with its great accumulation of sediments. From the way in which the folds and thrust planes lie it is evident that the major forces concerned were developed as the consequence of a slow, resistless movement of the sides of the geosyncline towards one another. This seems to have been accompanied by a plunging movement which took the deeper deposits and their foundations down to greater depths.

This plunging movement gave rise to interesting results

outside the main zone of activity. The adjoining portion of the earth's crust shared to some extent in the sinking and consequently became submerged. The Persian Gulf is an example of this, though it is not now so impressive as it must have been when the Armenian and Zagros mountains first came into being. At that time the gulf extended much farther inland in a north-westerly direction almost to the region around Damascus. Since then much of the gulf has been filled up by sediments brought down by the numerous rivers that rise in the mountains. Some of the profoundest depths in the Pacific and Indian oceans lie alongside the great ranges that skirt the seaboard of the American continent and of the equally great half-submerged ranges which form the backbone of the islands of Japan, of Sumatra and Java. These deeps are technically known as 'foredeeps'. The great plains of northern India occupy the site of a similar foredeep south of the Himalayas.

The question as to what were the causes which brought the sides of the geosyncline nearer together is still the subject of much discussion. According to one view it was brought about as the result of the cooling and consequent shrinkage of the earth. The basis of another view has been already referred to in connexion with the clotting of the sial into continental masses. The long, slow sinking of the floor of the geosyncline is considered to be due to the dragging action of deeply seated convection currents descending deeply into the earth beneath. As the currents increased in speed the sides of the geosyncline were drawn together and to some extent downwards, thus producing the plunging movements mentioned above. It is a fascinating and attractive explanation which satisfies some, while others suspend judgement.

Since the rocks that have been carried down in this way to great depth belong to the sial, they are lighter than the sima into which they have been to some extent drawn. In course of time the tendency to isostatic readjustment began to operate, and to resist the dragging-down action of the convection currents. The rate of flow of these slowed down, and the newly-formed roots rose by flotation and lifted the mountain crests to greater heights.

8

ROCK FRACTURES AND EARTHQUAKES

FROM what has already been said it is evident that the rocks are being continually subjected to stress and strain of varying strength in different directions; as the result of sinking here, rising there, and squeezing yonder. At the junction between two areas that are being pressed in opposite directions, either up and down or sideways, the rocks become more and more strained as the pressures increase. They are like a thick stick that is being broken for a bonfire, they are strong enough to resist breaking for some time, but at last a limit is reached. Then quite a small factor, a high tide, or an increase in barometric pressure, may suffice to push the strain beyond that limit. The accumulated strain is suddenly released, by the snapping of the rocks, and the two masses slip or grind past one another. The rocks around are jolted and vibrations travel outwards in all directions around and through the earth. The plane along which such a fracture has taken place is called a fault plane. In normal faults it slopes from the surface down towards the side on which the rocks have dropped. In collieries, quarries, and cliff faces such faults are often seen, and their abundance is permanent testimony to the numerous earthquakes that have shaken the region in past ages. Each fault may, however, represent many earthquakes for repeated slipping may take place along the same plane.

As seen in the last chapter, in some regions, especially where mountains have been formed, pressures have been exerted sideways. Just as when a card player pushes his cards together over a smooth table they slip over or under one another, so, when the rocks at last gave way, one slice mounted upon the other and was pushed over it slowly, irresistibly, 5, 10, 15, or even more miles. The plane along which it travelled was slightly inclined to the horizontal and is known as a thrust

plane or reversed fault because the upper slice has travelled up and not down the slope as in the case of a normal fault.

The depth at which the snap or slide takes place is the focus or centre of the earthquake which is produced. The point at the surface vertically above it is called the epicentre. The shock reaches the surface at this point first and then, like a wave that has been started by throwing a stone into a quiet pool, it spreads outwards in concentric circles. In the case of a very severe earthquake the wave may be seen actually travelling as an undulation across the landscape; creating a terrifying sense of a world that has lost its stability, and of the approaching end of all things. Just as a slight jerk of the hand, at one end of a billiard cue, sends a ball at the other end coursing across the table, so the jolt imparted to the rocks below ground sends the soil and stones flying from the surface. These phenomena have been aptly described by an observer who was out in the open country in Assam during a severe earthquake. The passing wave threw him to the ground. As he lay there he saw the land heaving, and from the hillside the soil and stones were scattered like a poodle coming up out of the water and shaking itself.

When such events happen in inhabited areas they are disastrous. Buildings are shaken to and fro and, unless they are specially built, are seriously damaged or even collapse. Away from the epicentre the shock strikes them obliquely upwards. Entering the foundations on one side it travels towards the opposite eaves causing cracks in the walls at right angles to its course and, as it emerges, projects the upper corner of the house into the air and casts it to the ground. In the early days of earthquake study the angles which these cracks made with the ground, at points equidistant from the epicentre, were carefully measured. By projecting lines at right angles to the cracks into the ground it was possible to estimate approximately the depth of the focus below the surface.

While much was learned about earthquakes from such observations made in the open country and in populous areas, it was realized at the end of the nineteenth century that, if danger to life and damage to buildings were to be reduced or even avoided, much more detailed and accurate information

was needed. It was hoped that by more careful investigation it might become possible to forecast the coming of earthquakes n time to warn the possible victims. Moreover, such knowledge was necessary if buildings were to be suitably designed and constructed to resist shock. A pioneer in this more serious study of earthquake or the science of seismology was J. Milne, who made Japan the centre of his operations.

An earthquake, however, comes like a thief in the night, without warning. It was necessary, therefore, to invent instruments that neither slumbered nor slept. Some devices were quite simple. One, for instance, consisted of rods of various lengths and thicknesses which would stand up on end like ninepins. When a shock came it shook the rigid table upon which these stood. If it were gentle, only the more unstable rods fell. If it were severe, they all fell. Thus the rods by falling, and by the direction in which they fell, recorded for the slumbering scientist the strength of a shock that was too weak to waken him and the direction from which it came.

But instruments far more delicate than that were needed if any really serious advance was to be made. The ideal to be aimed at was to devise an instrument that could record with a pen on paper the movements of the ground or of the table, as the quake passed by. While I write my pen moves, but the paper keeps still. With practice, no doubt, I could in time learn to write by holding the pen still while the paper moved. That sounds a silly suggestion, but that was precisely the idea adopted in some of the early instruments (seismometers) for recording earthquake waves. But when table, penholder, and paper are all moving how is it possible to write legibly? The key to a solution of that problem lay in an everyday observation. Why does a person standing in a bus or train tend to fall when a sudden start is made? It is because his feet move on, but his head stays still. A simple experiment will help us a little further. Tie a heavy weight at the end of a long piece of string. With the hand held high in the air hold the string so that the weight nearly touches the ground. Now move the hand to and fro and around but not up and down. It will be found that the weight moves but slightly or not at all. Imagine a pen attached to the weight

in such a way that its point rests upon a piece of paper on the floor. Imagine an earthquake shock shaking the floor, the paper, you, and your hand. In the midst of all this movement the weight and the pen would be still. But as the paper moved from side to side under the pen point its movement would be recorded in ink upon its surface. It was upon this principle that the first instruments were made, but the paper was wrapped round a drum which rotated slowly. As long as all was still the pen drew a straight line, but while the drum was being shaken the line that the pen was drawing wriggled from side to side. The apparatus thus described, however, records only the horizontal component of the wave movement, which is, in fact, much more complicated. If we could actually see the path described by a particle, such as a sand grain in the rock, it would be more like that of a bluebottle buzzing round the room; it would be up and down, to and fro and from side to side. Instruments have been devised and can be so placed that all three elements can be recorded in different graphs.

When the instrument is situated at more than 700 miles from the earthquake centre, the graphic record shows three waves arriving one after the other at short intervals. The first records the arrival of longitudinal vibrations. The second marks the arrival of transverse vibrations which travel more slowly and arrive several minutes after the first. These two have travelled through the earth. It was from the study of these that so much was learnt about the interior of the earth. The third, or main, wave is the slowest and has travelled round the earth through the surface rocks.

From newspaper reports and wireless broadcasts the occurrence of serious earthquakes in populated regions is soon made known to the general public, and consequently certain parts of the world such as Japan, Italy, and California are associated with earthquakes in the popular mind. These reported quakes are, however, only a very small proportion of those which take place in less well-known regions. Seismometers, situated in laboratories at many different spots about the world, show that earthquakes occur every few minutes, including severe ones which take place about every fortnight.

By combining the results derived from several records the depths at which the centres of disturbance occur can be ascertained. The great majority of shocks felt in Italy have been shown to emanate from depths up to 5 miles from the surface. A few have come from greater depths down to a maximum of nearly 500 miles.

In like manner the precise position of each centre of disturbance can also be ascertained, even though it may be situated in some out-of-the-way spot far from the habitations of man, or deep down below the ocean floor. The locations of a great number of these spots have been fixed and plotted upon maps. From the study of these much information has been gained about the distribution of earthquakes which have taken place in recent years.

From what has already been said about the relation between earthquakes and rock fractures it may naturally be assumed that during the present age they will occur most frequently along those zones of the earth's surface where, in late geological times, the rocks have been subjected to great pressures and heaved up to form the loftiest mountain systems. It has been noticed already that these movements began to act gently some 150 millions of years ago, and developed with increasing vigour until they reached a climax 120 millions of years later. It is not surprising, therefore, that though, during the last 30 million years, they have declined rapidly, they still rumble on to some extent, especially along the front line where the mountains descend steeply to the plains or even to the floor of the sea.

An inspection of such distribution maps shows that the majority of the disturbances which have occurred during the last half-century have indeed taken place along these mobile belts of the earth's crust. These are marked out to-day by the presence of the major mountain systems of the world. Looking at that side of the globe described above as the land hemisphere, these mountains are seen to lie along two irregular circles; a northern and a southern which impinge against one another in the mediterranean latitudes. Together they form a crude figure of eight. As will be seen in the accompanying

diagram, this figure encloses practically all the land on the face of the globe.

Earthquakes are not distributed uniformly along these circles. Many of them, including some of the most severe ones,

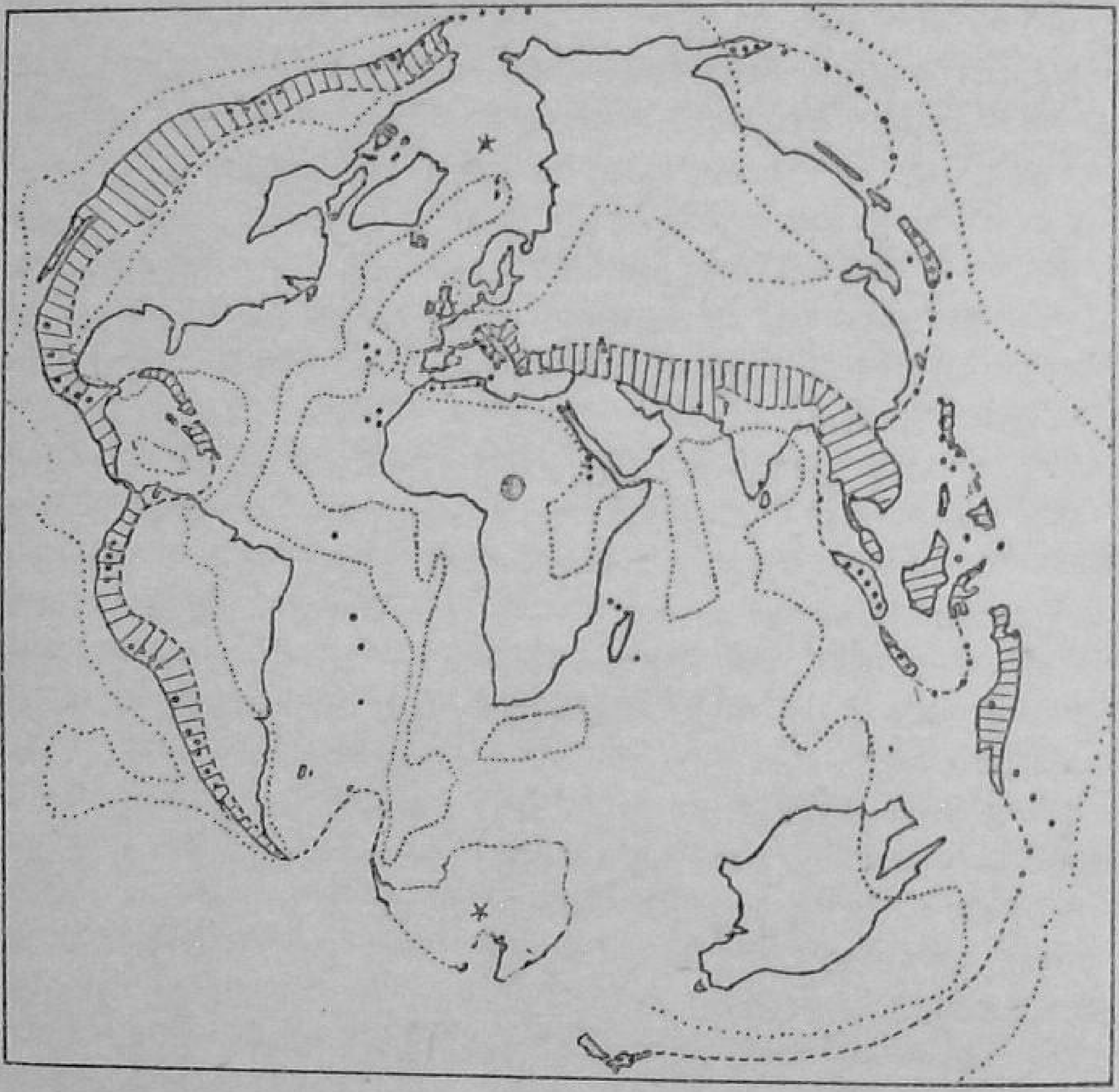

FIG. 6. THE DISTRIBUTION OF MOUNTAINS, VOLCANOES, AND EARTHQUAKES

A diagrammatic map showing the distribution of mountain systems produced by earth movements in Tertiary Times (shaded), of volcanoes living and extinct (large dots), and areas with earthquake centres (enclosed by dotted lines). Stars = the poles

have occurred along the eastern fringes of the Philippines and Japan, where the steep front of half-submerged mountain chains plunges down to the profoundest deeps of the Pacific Ocean. Nearly 90 per cent of the earthquakes occur along the

junction of these two irregular circles particularly in Italy and Asia Minor, Mexico, and the Philippines with Japan. A belt that is subjected to minor earthquake activity occurs along the central rise in the floor of the Atlantic which emerges at the surface in the Canary Isles, Iceland, and Spitzbergen.

Another belt is associated with an extraordinary series of valleys ranging approximately north and south for some 3000 miles through Syria, Palestine, and Central Africa to the Zambesi. These valleys are exceptional in that they are not due to the erosive action of rivers assisted by rain and frost. They consist of long strips of country, varying in width from 25 to 50 miles, which have dropped down below the general level of the country on either side. Thus the journey from Jerusalem to Jericho, which is situated on the floor of one of these valleys, involves a steep descent of 4000 feet. They are bounded along the sides by great lines of fracture or of faulting. It was formerly believed that these were normal faults which sloped towards the slumped strips. The fact that the country which adjoins them slopes away from the valley suggests that the whole was once raised up into a long low arch that cracked along two lines parallel to the crest, which dropped down between them. Recent investigations, however, provide a very different explanation. According to this they are the outcome of intense pressure exerted from the sides, somewhat similar to the much greater pressures which were concerned in mountain building. In this case the rocks were so rigid that they bent only slightly. They then gave way; first along a crack that sloped away from the centre of the crest, so that the block of country on that side was thrust up the slope, and the ground over which it slipped went under. As pressure continued, a companion fault of the same kind took place on the other side of the arch. If this be true, then the crest did not merely 'drop' but was pushed down under the overhanging edges of the broken arch. They did not, of course, ever actually overhang, for the edges, being unsupported, broke down into the valley in a succession of landslides, thus giving the appearance of a series of normal faults which, if this explanation is correct, deceived the early workers.

In one place, north of Ruwenzori, a terrace has been found on the side of the valley some distance above the floor. As this terrace is covered with alluvium, which could only have been formed on the floor of the valley, it is evident that the side has been pushed up comparatively recently; and that movement is still going on along the thrust plane. No doubt such movements account for the earthquakes which occur from time to time in the region of these valleys.

9

DENS AND CAVES OF THE EARTH

In the days of King Alfred the Great the city of Nottingham was known as Tigguocobauc or 'the place of caves'. Even as recently as the beginning of this century the rocks beneath some parts of the city were still honeycombed with caves. Indeed it was sometimes necessary, before building a house, to make sure by boring that it was not being built upon a cave. Though many of the caves have been filled in or destroyed some still remain and are used for storage and other purposes.

Much of the rock in the city area is a soft friable sandstone which rises here and there into low cliffs or bluffs. In early centuries dwellings were excavated in the faces of these. The same practice prevailed in other parts of England where there is a similar kind of sandstone. But one of the most striking examples in the world of such man-made caves is in Transjordan, in the ancient city of Petra, where not merely ordinary dwellings, but palaces and richly decorated temples have been carved out of the solid rock.

Not less interesting are caves that have been formed by natural means. Such, for example, are the caves in the cliffs at the sea-side beloved by holiday-makers who, for the time being, hark back to the mode of life of their prehistoric ancestors. Here in the caves they shelter from passing showers or from the hot sunshine. Here they have their picnic meals and change for bathing. When the tide comes in they scramble up the cliff to

some vantage point where they can watch the waves splashing against the base of the cliffs.

During storms the waves strike the rocks with much greater force. Armed with sand and shingle, picked up from the beach, they grind away at the rocks and undercut the cliff. Thus undermined portions of the cliff collapse on to the beach and supply the waves with further ammunition for their destructive work. In addition the wave, as it falls back from the face of the cliff, exerts a sucking action that loosens and plucks out blocks. Here and there where the rocks have been weakened by major cracks and fractures this grinding and plucking action proceeds with greater activity and the cracks are widened into caves which in turn make way for the waves to go on excavating still farther into the cliff. Meanwhile parts of the roof of a cave may fall in and go on doing so until a passage is made through to the ground above. At high tides the spray from the waves breaking inside the cave rises through this hole like steam from a 'devil's cauldron'.

When, as often happened in the past, earth movements took place which lifted the land to a greater height above sea-level, then the beach with its background of cliffs and caves became a 'raised beach'. Henceforth it was beyond the reach of the sea even at the highest tides. Such caves become the haunts of wild beasts, the dens to which they can retire with their prey and feed their young. In prehistoric times men of the Old Stone Age evicted the beasts and lived in the caves with their families, and used them as bases from which to set out on hunting expeditions. Here also, in the innermost recesses, they sometimes buried their dead.

Caves and caverns have, however, been made far inland on a much more extensive and grander scale by the action of underground waters upon limestone. In order to explain how this is done it is necessary to recall some familiar facts. Every housewife knows the difference between soft and hard water. Rainwater is always soft and lathers freely with soap. Hard water does not lather so easily but makes scum instead. Moreover when hard water is boiled it deposits lime on the inside of the kettle which, after frequent usage, becomes lined with a hard

crust or 'fur' of lime. Nevertheless that same water when it first fell from the clouds was also quite soft. Descending as rain it dissolved carbon dioxide from the air. This made it slightly acid and able, as it percolated deep down into the ground, to dissolve lime from the rocks through which it passed. When eventually it issued forth at the surface as a spring it had become hard.

Hard waters are particularly characteristic of areas where limestone rocks predominate. In such areas the water often seeps out slowly along valley sides and makes the ground permanently wet. Here mosses grow in profusion. As the water trickles over them they extract the carbon dioxide from it. The water can now no longer hold the lime in solution and so deposits it over the surface of these little plants like a 'fur', which accumulates over the mossy mass until a porous rock called tufa has been formed. Tufa is often quarried and used for making rockery gardens.

Another factor which plays a part in helping water to dissolve limestone is pressure. As the water descends into the rocks the pressure upon it increases and enables it to dissolve still more of the rock. When, however, the water escapes at the surface once more it is released from pressure and, again, the lime it holds in solution is set free. At holiday resorts in limestone districts springs are often exploited under the name of 'petrifying wells'. For the payment of a small fee the holiday-maker may put any object he pleases into the water from a bird's nest to a toy pistol, and leave it there for a day or two. On his return he finds it completely encased in lime. He may think it has been turned to stone, but that is not the case for, if it is accidentally broken, he finds the nest and the eggs inside unchanged.

As this flow of water through the limestone has been going on for ages, it is evident that large quantities of the rock must have been dissolved and carried away from the district. In order to picture to ourselves the total effect of this it will be helpful if we follow the water in its journeying through a massive layer of limestone. At the outset the streams, produced by rain, flow over the surface of the ground as they would do over

any other kind of rock. In addition to wearing their beds by grinding them, with rolling gravel and boulders, they also deepen them by dissolving the rock. In this way, therefore, a normal valley system is developed.

Limestone, like other rocks, is traversed by two systems of cracks, by bedding-planes and joints. The former separate one layer of rock from another. The latter are perpendicular to these planes and cut through each layer, thus dividing it into more or less rectangular blocks which fit closely against one another. Sometimes a major crack occurs in the form of a fault fracture which traverses both these systems.

All over the surface of the limestone, on the high ground and along the valleys, some of the rain and river water percolates into these cracks. As it does so it dissolves the limestone on either side and so widens them, thus creating a more open passageway for the flow of water. This widening naturally takes place more rapidly where two cracks cross one another. At such points vertical pipes are formed down which the water flows in still greater quantity. At the surface the ground around the pipe is widened out into a funnel-shaped depression known as a 'swallow hole', into which a quite considerable stream may flow and disappear, and henceforth pursue its course underground.

At the same time a similar process is at work along the bedding-planes. In this case, however, the water flows only over the top surface of the lower layer and dissolves out of this a miniature valley system underground with tributary and main streams or rivers. Blocks of rocks now and then fall from the upper layer or roof and are smashed by the fall. These are driven along by the force of the stream and help to grind the channel still deeper. In this way the narrow chink which at first separated the two layers of rock becomes a spacious cavern. Thus beneath a peaceful countryside there may be a hidden landscape with caves and corridors, rivers, lakes, and plunging waterfalls.

In course of time this excavating process reaches down to the water-table, to the level below which every crack and crevice of the limestone is full of water. When this happens the

underground stream can excavate no more. Eventually both stream and cavern come out to the surface at the foot of a cliff or in the side of a valley. As with sea caves, so with these caverns earth movements may take place and add a new chapter to their story. If the region be uplifted, it may be only a few feet, the water-table sinks to a lower level. Both underground and surface streams begin work once more. The latter excavates its bed down to the new level. The former dissolves new passageways through cracks below the old channel and leaves its former caverns high and dry with their openings up on the valley side.

Old Stone Age man in the course of his wanderings discovered some of these caves and occupied them for long periods of time. The ashes from his fires, the bones and refuse from his feasts, the dirt trodden in on his return from the chase, accumulated upon the floor. Implements, used in hunting deer, or for skinning and cutting up their carcasses, were sometimes dropped and lost. When the climate changed and became too cold he migrated and went to live elsewhere. The cold then became so intense that severe frosts penetrated even to the inside of the cave and shattered the rock in the roof and the sides. Blocks of stone fell down to the floor.

With the return of slightly milder and moister conditions water percolated through the rocks above and became charged with lime. Some of it, trickling down the walls and dripping from the roof, deposited lime over the floor and cemented the stones together, thus sealing up the surface of the débris under a translucent covering of lime, described as travertine. All the traces of man's occupation of the cave were protected thus from being disturbed when prehistoric man returned and reoccupied the cave. Once more the débris and relics of his activities accumulated. The sequence of events briefly outlined above was repeated several times and thus records were made and preserved which spanned periods of time covering 100,000 years or more. It will be seen later that many caves in which such records were concealed have been discovered and explored in limestone areas in England, France, the Pyrenees, and around the shores of the Mediterranean.

Limestone landscapes having the peculiarities described above have sometimes played a prominent part in history and literature. An outstanding example exists in Palestine. There a mass of limestone makes that block of upland country which lies between the Mediterranean and the Jordan Valley. On the west it rises to a height of 2000 feet above sea-level. On the east it drops steeply nearly 4000 feet in fifteen miles to the shores of the Dead Sea. At the foot of these slopes underground streams come forth from their gloomy caverns out into the brilliant sunshine. Seven such streams flow across the plain north of the Dead Sea and, saving it from being a desolate desert, have made of it a garden of gardens which the ancient writers described more picturesquely as 'a garden of the Lord'. No wonder that Lot, when the choice was put before him, chose that fertile plain rather than the barren upland. This, the Judaean upland, is riddled with caves. Here and there the roof of a main cavern has collapsed and in its place is a ravine-like valley open to the sky, with its sides punctured by the openings of caves.

In summer the valleys are dry, but in winter they laugh and sing with the music of running water. These were the surroundings in which Saul hunted David 'like a partridge in the mountains'. The stories of his adventures in and around these caves have thrilled many generations of boys and girls. Here it was that Judas Maccabeus and his brethren made such extraordinary tactical use of their local knowledge that they defeated Roman armies twenty times as numerous as their own.

It is a fascinating thought that, as we stand and rest our eyes upon a peaceful downland clothed with pastures and woodlands and dotted with the dwellings of men, there may be deep below our feet a hidden landscape wrapped in darkness, with caverns and tunnels for valleys; with caves whose dome-like roofs cover lakes unruffled by wind. Some of these caves exhibit scenic features, quite unknown above ground, created by water saturated with lime trickling down the walls and dripping from the roof. Each drop seems to pause before it falls and tends to evaporate and to lose some of its carbon dioxide. Some of its lime is consequently left clinging to the roof. This

process is repeated indefinitely and gradually there is constructed an icicle-like pendant of lime known as a *stalactite*. As the drop falls through the air more water evaporates, more carbon dioxide is lost and more lime is released to be deposited upon the floor below. Gradually a pinnacle is built upwards. This is known as a *stalagmite*. Sometimes the stalactite and the stalagmite meet and join to form a column that rises from floor to ceiling. Often this is so solidly built that if struck with a stick it rings like a bell. Meanwhile films of lime, formed in a similar way, are spread over the wall and are hung like translucent curtains from the roof or drawn up like flimsy veils from the floor. When such a cave is lighted up artificially with cunningly arranged lamps it presents a scene of beauty that is almost breath-taking. No wonder that the close proximity of such a cave to a holiday resort proves itself to be a valuable asset to the owner.

We owe our knowledge of all these marvels to venturesome spirits who spend their spare time 'pot-holing', who enjoy risking neck and limb by scrambling down into these stygian realms and exploring their secret ways. Discoveries of outstanding interest have been made by these speleologists in Austria, New Mexico, and Kentucky. In the plateau of Kentucky hundreds of caves have been found including the world-famous Mammoth Cave of Kentucky which is said to extend 30 miles underground.

While men and wild beasts visit or make temporary homes in caves that lie near the surface, other more lowly creatures, some of them allied to frogs and newts, have penetrated far into some of the largest caves such as those in Austria and Kentucky. There they feed upon organic débris that is swept from the outside world by streams that have disappeared from the surface down swallow holes. Here they have lived for generations and become adapted to living in perpetual darkness. Their sight has gone, but their sense of touch has developed and their legs and fingers have become elongated into sensitive tactile organs. In the absence of sunshine, which encourages the development of pigments in the skin, their bodies have become coloured a dirty white. The advanced

state of these changes is an indication of the great numbers of generations that have followed one another in these ultra-gloomy surroundings. As if to emphasize this, other creatures, living side by side with them, have these peculiarities only slightly developed. It is usually assumed that these are more recent arrivals.

10

PETROL, OIL, AND WATER

PETROL, Oil, and Water – these are the three essential needs every motorist must attend to before he sets off on his day's journeyings. Of these the last is the most ancient need, for no human being can live without it. Fortunately it is found in abundance in lakes and streams and at places where it gushes out of the ground in springs. Even where these are inconveniently far from camps and dwellings adequate supplies can often be obtained by digging wells. In this case, however, everything depends upon the nature of the rock beneath: some rocks are generous and part readily with the wealth of water they contain, others are miserly. Clay belongs to the later category, though it holds more water in its tiny pores than any other rock, its hold is tight, and its yield of water is grudging. The best thing to do with a well that has been unwittingly dug in clay is to fill it up and try elsewhere. That elsewhere may be a coarse sandstone. Looked at with a magnifying glass, sandstone is seen to be made up of grains of quartz and other minerals, each rounded like a minute pebble. Just as the pebbles in a heap merely touch one another at a few points, thus leaving open spaces between them, so is it with the grains in a sandstone. Rain falling on to sandy ground soaks into the spaces and flows along the little channels they form in the rock below. Where rock is broken by cracks these also become filled. When, therefore, a well is sunk into the sand rock, the water flows freely into it and fills it up to a certain level. The surface of the water thus marks the position of the 'water-table'; that is to

say the boundary between the lower part of the rock which is saturated with water and the upper part which, except when rain is falling, is practically dry. During periods of heavy rainfall the water-table rises and so does the surface of the water in the well. In dry weather the reverse movement takes place.

With the growth of large towns the supplies of water from such 'shallow wells', as they are called, has proved quite inadequate. In past centuries rivers and streams were extensively used as supplies of water for drinking and cooking. To-day, however, in thickly populated districts the dirty water which runs off the streets or has been put to domestic and industrial uses finds its way into the rivers and renders them quite unfit for human consumption. Public authorities must accordingly search for supplies of pure water elsewhere. Naturally their attention turns to waters in the open country, preferably where it is wild and thinly populated, and the chances of pollution are at a minimum. Usually upland and mountainous regions are the best for the purpose, and have the added advantage that there the annual rainfall is higher than in the lowlands, where the cities and towns are usually placed. The problem of tapping those supplies is, however, complicated by 'riparian rights'. No matter how powerful a great corporation may be, it is not allowed to do anything that will damage the supplies of farms and villages situated downstream from the site of the proposed waterworks. Attention, therefore, turns naturally from the water which flows normally all the year round to the vast volumes of water which run to waste and are even a grave source of danger in times of flood.

The most obvious procedure is to build a dam across the valley somewhere in its upper reaches. With this the flood waters can be held up while sufficient water is allowed to escape downstream to maintain the normal supply to the little folk. The first step is to find a spacious valley, preferably one which, because it narrows at some point, is already partially dammed by natural means. The length of dam required and consequently the total cost of erecting it are thus correspondingly reduced.

Having found such a valley the next problem to settle is whether it will hold the water or is vitiated by the presence of natural leaks. For example, its floor and sides may consist of porous sandstone, or be crossed by beds of limestone or broken by lines of faulting. The pressure of water in a deep reservoir is sufficiently great to enable it to force its way through such leaks into adjoining valleys or under the foundations of the dam into the lower stretches of the same valley. Having found a practically watertight valley, the engineer sets to work and there we will leave him at it.

A valley that already holds a lake is evidently quite suitable and sometimes further use is made of it by building a dam upon the natural barrier which will raise its surface level higher. By this means the flood waters are held, and the capacity of the lake greatly augmented. Birmingham has its reservoirs in the Welsh mountains in Radnorshire. Liverpool draws its supplies from Lake Vyrnwy in North Wales, Manchester from Thirlmere in the Lake District, New York from lakes up in the Catskill Mountains.

Water is put to other uses besides public consumption. Natural waterfalls, and the overflows from reservoirs are now extensively used as sources of power; for driving turbines and, through them, great dynamos that can produce electricity for lighting, heating, and multifarious industrial purposes. In mountainous countries, like Scandinavia and Switzerland, this has been the practice for many years. More recently, in relatively level country, giant falls like those of the Niagara and the Zambesi have been harnessed. In areas less favoured by the possession of natural falls artificial ones are being produced by building dams. A striking example is provided by the Great Boulder Dam which has been built in the state of Nevada. A quite different purpose is served by the Aswan Dam in Egypt. This holds up the flood waters of the Nile and enables them to be used for irrigating great areas of fertile, but waterless, soil.

Hitherto our attention has been directed mainly to the exploitation of surface waters by large corporations. Smaller communities find it more convenient and less costly to tap

underground supplies. For many isolated farms and hamlets shallow wells are still the only available sources of supply.

The history of water supply for the city of Nottingham neatly epitomizes the whole problem. This city is situated close to the River Trent, the waters of which were once so clean and fresh that, until comparatively recently, it was not infrequently visited by salmon and was much favoured by trout and lamprey. Up to the middle of the nineteenth century the city drew all its water for human consumption from the Trent. To-day pollution has put that quite out of the question. As already noticed

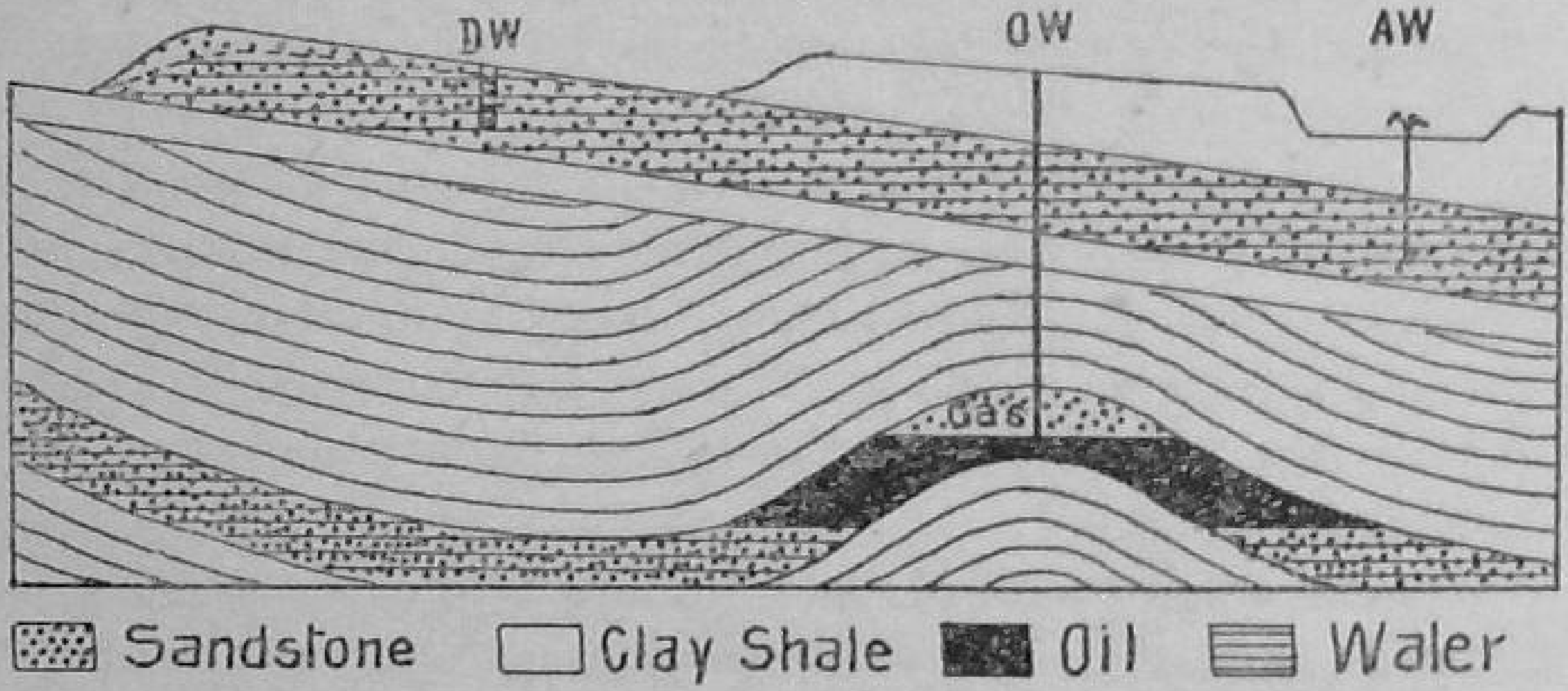

FIG. 7. THE NATURAL STORAGE OF WATER, OIL, AND GAS

Generalized geological section through an area where water, oil, and gas are stored in the rocks. D.W. = deep water well; A.W. = artesian well; O.W. = oil well

much of the city is built upon a sandstone 300 feet thick and so porous that it holds a quarter of its own volume of water. In 1857 the city authority sank its first deep well and obtained over 900,000 gallons daily. Various manufacturers followed suit and won for themselves an abundant and very cheap supply for all their processes. This increased demand upon the underground reserves naturally caused a decline in the supply from the first well. Meanwhile, with the growth of the population, the daily demand increased. Consequently new wells have been sunk farther and farther north out in the countryside, where the same rock outcrops over an extensive area.

Eastwards the sandstone dips down from the surface and passes under a thick covering of impervious clay rock. Though this water-bearing sandstone plunges down to a considerable depth below the surface its reserves of water can still be tapped by sinking boreholes through the impervious covering of clay. Such borings have been made at spots lying at a lower level than the water-table in the outcrop. The result of this has been that the water flowed freely up the boring and gushed out at the surface. In this case, therefore, the cost of pumping was eliminated naturally. Such water is said to rise to the surface under 'artesian pressure' and the well is described as an artesian well. There is an interesting addendum to this story. Other large towns which, like Nottingham, are situated in the basin of the Trent, have no such valuable underground reserve. Their population has also grown and with it the demand for more water. They, therefore, decided to establish reservoirs in the uplands of Derbyshire. As part of its 'riparian rights' Nottingham claimed a share of that water. By thus augmenting their underground supplies the City Fathers wisely ensured adequate supplies against further growths of population.

The city of London for many years depended largely upon artesian supplies. This was made possible by the fact that it is situated in the lower part of the Thames basin. The middle of this is underlain by a thick carpet of clay resting upon a massive layer of chalk 1000 feet thick. Beneath this there is a porous sandstone, called the greensand. These two layers of rock slope upwards from the middle of the basin and rise, like the sides of a saucer, to form belts of high ground along the north and south margins. Much of the rain which falls upon this ground sinks into the chalk and sandstone and keeps their pores and fissures filled with water. When, therefore, deep borings were put down in the centre of the basin, they punctured the impervious covering of clay and, for many years, abundant supplies of artesian water were obtained. In subsequent years the increasing number of borings led to a marked reduction of the artesian pressure and supplies of water had to be sought in other ways.

These Nottingham and London examples are not merely of local interest, for they illustrate the problems and methods of obtaining supplies of water that are applicable all over the world.

Many of the sedimentary rocks were originally laid down in the sea. Even now they still hold some of that marine water in their deepest levels. There it has been held, imprisoned in the pores, together with other water and has been stagnating for ages. If more water is pumped from deep wells and borings than can be replaced by rainfall some of this dormant water may be drawn in and thus spoil the quality of the rest.

Petrol and some types of oil are refined products extracted from rock oil or petroleum. This liquid, like some of the water just mentioned, has also been imprisoned in the rock for ages. In its raw state its colour varies from pale yellow to dark brown, and may have a greenish tinge. Chemical analysis, backed by geological observations, indicates that much petroleum had its origin in minute plants, lowly algae which lived in the surface waters of ancient seas. Their dead remains accumulated in large quantities on the sea floor in areas where, for various reasons, the water was stagnant. In the absence of oxygen these organisms did not undergo the normal processes of decay but underwent chemical changes leading to the formation of a complex mixture of hydrocarbons. These, in the case of the lightly coloured oils, are akin to paraffin, and, in the case of the darker oils, to naphthalene.

The richly organic muds thus formed became buried under clayey and sandy deposits, and have remained sealed up under conditions of temperature and pressure which favoured the continuation of the chemical changes already begun. Gradually the oil seeped out and found its way into more porous rocks such as sandstone and fissured limestones. Here it shared the storage space with water. In as much as oil and water are bad mixers they separated out from one another; the oil floated to the top and came to rest above the water.

If the oil is not to be lost, it is a primary essential that the porous layer of rock containing it should be sealed up, above and below, by beds of clay or some other rock that is imper-

vious. Picture such an arrangement of layers becoming buckled into upfolds and downfolds. The water will naturally sink into the latter and the oil rise into the former. Quite often the chemical changes lead also to the formation of 'natural gas' such as helium. This rises above the oil and occupies the crest of the fold. Thus 'pools' of gas and oil occupy the crest and sides of the fold respectively (Fig. 7).

It is evident that the search for such pools in oil-bearing regions must begin with a study of the rocks at the surface; their nature and the directions in which they dip below the ground. From such indications it is possible to discover the positions of upfolds and so settle which are the most suitable points at which to sink borings for tapping the pools. There are, of course, a number of other possible arrangements of rock which lead to the formation of pools, but the same general principles of accumulation and distribution apply to them also.

Quite often natural ways of escape have been opened out. The rocks have been broken by a fault, or the crest of the upfold has been uncovered. The gas then escapes. Sometimes, as at Baku, on the shores of the Caspian, it has caught fire from flashes of lightning and has gone on burning for a long time. Again the oil may seep out on to the surface. There its volatile constituents evaporate and pools or even lakes of pitch or bitumen accumulate as in Trinidad and at Los Angeles. At the latter place animals have been attracted by the sheets of water that often lie upon the pitch and have been entangled and finally engulfed. Among the many skeletons that have been redeemed during the exploitation of the pitch some belonged to creatures, like *Smilodon*, the sabre-toothed tiger, which have been extinct for 50,000 years or more. This provides striking evidence of the great resources of that underground reservoir of oil which could go on leaking for so long a time.

II

THE EVOLUTION OF A TIME SCALE

ABOUT the year 1851 the Geological Survey of Great Britain moved from Whitehall into specially built premises in Jermyn Street which provided room for both staff and collections. After little more than eighty years, in 1934, it moved again into still more spacious accommodation in South Kensington. The story goes that, when the wall cases at Jermyn Street were taken down, some of the spaces behind them were filled to a depth of two feet with impalpable London dust. That two feet of dust was a scale which represented some eighty years of geological time, during which the geological process of dust settlement was at work. In a normal household the scale is no sooner begun than it is destroyed with a duster. Nature also often destroys her scale, but sometimes she preserves it.

Mud is wet dust, and mud is being constantly carried off the landscape by rivers and deposited either in lakes or in the sea. There it accumulates and becomes subjected to pressure, under the weight of further accumulations of mud. Under this it is compressed and much of the water in it squeezed out. The sloppy mud is thus converted into stiff clay of which perhaps one foot might be taken as the scale for eighty or even a hundred years. In course of time that clay may be buried under hundreds or thousands of feet of other rocks. Under this much greater pressure, it is still further compressed and more water squeezed out, until the clay becomes a shale, a rock which breaks easily into flat flaky pieces. It is not unreasonable to suppose that two feet of mud might eventually become two inches of shale. For shale the scale would then be two inches for eighty or a hundred years.

'Perhaps', 'not unreasonable', 'suppose', 'eighty or a hundred' – this is far from being the language of an exact science, but this was the only type of evidence for length of time which the early geologists had before them. Of course two feet

of dust, one foot of clay, two inches of shale do not sound very impressive. Nevertheless, out yonder, on the landscape, may be found accumulations of clay 500 feet thick; mountainsides of shale a thousand feet or more high. It is there, in the field, that the geologist becomes filled with a sense of the vast stretches of time represented by the rocks.

Clay and shale are not the only rocks that have been formed by settlement of sediments in water. There are sandstones and grits hundreds of feet thick producing scars and crags correspondingly high. There are limestones, such as chalk, consisting of the comminuted remains of inconceivable hosts of tiny shells no larger than the head of a pin. Some early geologists ventured to estimate that one inch of chalk represented a century of silent pulverizing of these shells and accumulating of the powder. The normal thickness of chalk in England is 1000 feet. Does it really matter whether an inch represents a century more or less? The consideration of that 1000 feet of chalk expands our conception of time in terms of past ages as much as the calculated distances of the sun and fixed stars expand our sense of space.

When the early geologists combined their observation on, and measurement of, the rocks in different parts of England and Wales they found that the thickness totalled up to about 20 miles, and thought that perhaps this great accumulation might represent 100 million years. To the present generation that seems almost paltry; but to a generation brought up to think that the world itself was created in the year 4004 B.C., it was breath-taking and revolutionary.

Charles Darwin with his sweeping view of the infinite variety of forms of life and of the slowness of the processes of evolution, by which they were produced from very simple beginnings, boldly claimed 400 million years. Then a storm burst which to those who lived through it seemed terrific, but to us to-day it seems no more than the stirring of a spoon in a cup of tea.

To physicists born and bred in a Laplacian atmosphere of ideas it seemed that they could easily settle the question raised by geologists. The earth was once a hot liquid globe which lost

its heat steadily by radiation and became solid. The rate at which its heat is still being lost could be directly and accurately measured. On the basis of these measurements calculations were made which gave the span of the earth's past life as 4 million years. The process of cooling would still go on in the future and finally the world would become an ice-covered waste. Breathing this atmosphere of thought Wells wrote his novel, *The Time Machine*, which to-day is a fossilized relic of an interesting phase in the evolution of an absolute scale for geological time.

The geologists seemed defeated but, like Brer Rabbit, they lay low. After all, in human history, the precise date when a king came to the throne or when a statesman was in power is of little or even of no account. The fundamentally important aim of history is to discover the trends of social, economic, and other phases in human progress. The geologist also found quite enough to keep him happy in tracing the sequence of events in the earth's history and development. As long as he got the order right, the question as to whether they took place during a period of 10 or 1000 or even a million million years was interesting but of comparatively little importance. The actual progress he made in knowledge of that sequence was really very remarkable.

At a very early stage in the development of geological science a simple but sound principle was adopted for building up a relative, as opposed to an absolute, scale of time in terms of years. It is a principle unconsciously accepted in most walks of life. It is that when things are piled on top of one another – newspapers, books, rubbish – those that are underneath were laid down first, those on top were put down last. Speaking scientifically, this is known as the 'Law of Superposition'. Applied to rocks it means that in a quarry or cliff the layer at the bottom is the oldest; the one at the top, the youngest. There are, of course, pitfalls. When, for example, rocks have been over folded, in some parts of the fold the rocks have been turned upside down. Usually the geologist is too wary to be caught.

Each layer of rock records some information about the

state of affairs at that spot when that layer was being formed. It was a floor of the sea or of a lake, a swamp, or a desert. The fossils it contains provide a picture of the creatures which existed at that time. In brief, the sequence of time is thought of, not in terms of 'figures on a dial', but of layers of rock cropping out on the landscape. As already noted, these layers pile up to a thickness of many miles and that fact testifies to a vast period of time. It has been found very convenient in talking about the events in the history of the earth, and of the animals and plants that have lived upon it, to divide and subdivide this long stretch of time. Some British geologists of the early nineteenth century concentrated their attention on the oldest rocks they could find in Wales. There they found what were believed to be the oldest fossil-bearing rocks. To these they gave the name *Cambrian.* The base of these Cambrian rocks became a convenient datum level. All rocks below it came to be spoken of collectively as *Pre-Cambrian.* Other names are also in use but this will serve our purpose.

Most of the Post-Cambrian rocks contain fossils. The examination of these shows that animals were, from the outset, related to those that are living to-day. In many respects, however, they looked strikingly different and old fashioned. As time passed along, these differences decreased and eventually vanished. On the basis of these changes in animal life Post-Cambrian time was divided into three major divisions or ERAS.

The Palaeozoic Era (*palaios*=ancient), in which ancient-looking animals lived.
The Mesozoic Era (*meso*=middle), with creatures moderately like those of the present.
The Cainozoic or Cenozoic Era (*kainos, cenos*=recent), with creatures of modern aspect.

A relic of an earlier system of subdivision survives in the occasional use of the term Secondary for Mesozoic. Rocks formed during each era are called by the same name, thus Mesozoic rocks.

The eras are in turn subdivided into PERIODS and the corresponding rocks into SYSTEMS. The names used for these

Eras	*Periods and Systems*	*Approximate Dates in millions of years*
CAINOZOIC	QUATERNARY	
	Recent	
	Pleistocene	
		1
	TERTIARY	
	Pliocene	
		15
	Miocene	
		35
	Oligocene	
		50
	Eocene	
		70
MESOZOIC	CRETACEOUS	
		120
	JURASSIC	
		150
	TRIASSIC	
		190
PALAEOZOIC	PERMIAN	
		220
	CARBONIFEROUS	
		280
	DEVONIAN or OLD RED SANDSTONE	
		320
	SILURIAN	
		350
	ORDOVICIAN	
		400
	CAMBRIAN	
		500
PRE-CAMBRIAN ERAS AND SYSTEMS		
		2200+
GAP IN THE RECORD OF UNKNOWN LENGTH		
		3000+
BIRTH OF THE EARTH		

may reflect the nature of the rock. Thus Cretaceous is derived from the Latin word *creta*=chalk. They may be named after the district where they were first fully investigated, thus Cambrian from *Cambria*=Wales, or Jurassic after the Jura Mountains.

The table on page 76 gives an outline of the geologist's relative time scale. Only those subdivisions which are referred to in these pages are mentioned.

Geologists had made great progress in the establishment of this relative time scale and with refining its details when physicists began to make discoveries which provided them with foundations for making a scale in terms of years, one which courtesy allows us to speak of as an 'absolute time scale'. They discovered that the atoms of some substances, such as uranium, were undergoing spontaneous disruption leading, on the one hand, to the release of radiant energy in abundance and, on the other, to the formation of inert elements such as lead.

The presence of these substances, in the rocks of the earth's crust, releasing energy which raised their temperature provided ample supplies of heat to balance that lost by radiation from the earth's surface. Here then was a process that could maintain the internal temperature of the earth at its present level almost indefinitely. The period of 4 million years which they had previously given as the age of the earth was, therefore, promptly and effectively put out of court.

It was soon realized that the change from uranium to uranium lead, and also other changes, provided a basis for estimating the length of geological periods in terms of years. They ascertained the rate of these changes with reasonable accuracy. Samples of rocks such as granite were carefully analysed to discover the amounts of uranium and of uranium lead they contained. Assuming that it was all uranium to start with, the time required for producing that amount of lead was calculated. The result gave the age in years of the specimen of granite and also that of the sedimentary rocks with which it was associated in the landscape.

Granites have been formed at many different periods in the past. From their positions in the sedimentary rocks their

relative ages were well known. With the aid of these physico-chemical methods their actual as well as relative ages were now obtainable. The close correspondence between the arrangements made by the two methods confirmed the values of this radioactivity method for dating the past ages. The figures given in the last column of the table are based upon this and furnish a sound approach to an absolute chronology for geological time.

Part Three: The Realms of Pluto

12

A RECONNAISSANCE

IN Greek Mythology Pluto was the god of the underworld where no sunshine ever penetrated. The dead were his subjects, and he was also the disposer of all wealth to mankind; for he owned earth's stores of gold and silver, of precious stones and valuable metals. The days of such engaging stories have gone, but echoes are still heard in university classrooms when the lecturer in geology begins to talk about plutonic rocks.

The geologist cannot descend to the realms of Pluto, but he has access to two sources of information which throw light upon the state of affairs and the events which happen in those depths. First and foremost are the volcanoes of the world in which processes and agents are at work that are strikingly different from those already studied above. Wind, rivers, sea currents are constantly shifting the materials of the earth's crust horizontally from one part of the surface to another. In volcanoes the material is being shifted vertically, from the deeps below up to the surface. The rocks produced by the former means are called sedimentary; those produced by the latter are eruptive. From the study of volcanoes and of eruptive rocks much may be learned about subterranean conditions, agents, and processes.

The other source of information lies in those areas where, as already seen, subterranean processes have raised parts of Pluto's realm up to levels at which surface agencies have removed their coverings and have laid them bare. This has taken place extensively in shield regions and in smaller patches situated in the cores of mountain belts of past and present ages.

The plutonic processes have long since ceased to work in those areas, but the evidences of their activity are still preserved. Sometimes in a great industry there is a lightning strike. The men down tools and leave their tasks in various stages of incompletion. An expert sauntering round the silent works can,

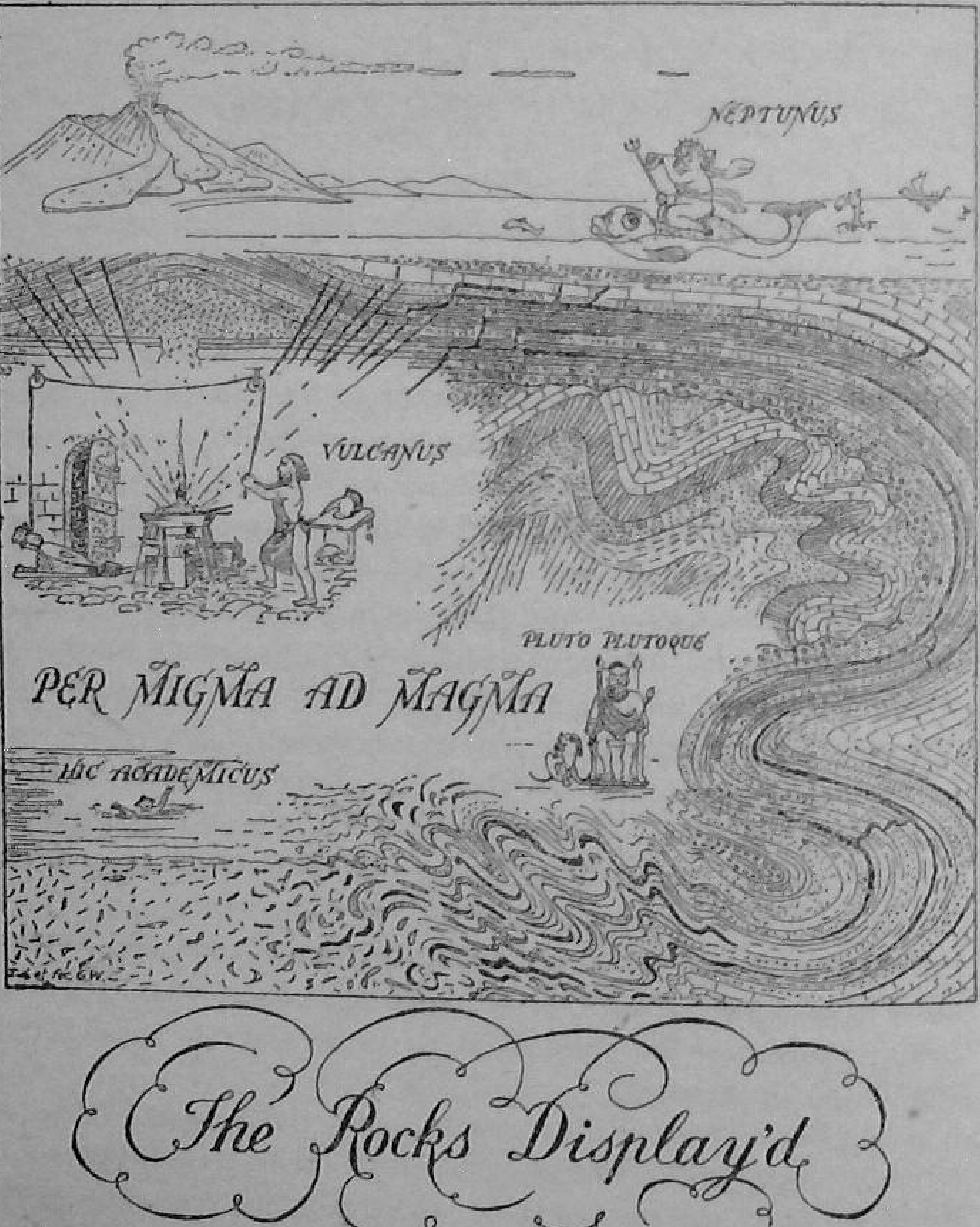

FIG. 8. (By Courtesy of Professor H. H. Read and the Council of the Geologists Association)

by careful inspection of each man's place, piece together an account of all the operations from start to finish. In like manner skilled geologists are gradually reconstructing the story of the ways in which eruptive and metamorphic rocks were made, and no doubt are still being made, deep down in the Realms of Pluto. They examine the structure and arrangement of the rocks on a large scale in the field. They collect rock samples for more detailed examination in the laboratory. A strategic advance was made into these phases of earth history when early in the nineteenth century a method was invented for grinding and polishing chips and slices of rock until they were so thin that they were as transparent as glass. Their examination under the microscope revealed intimate details in the make-up of these rocks which have thrown a flood of light upon their modes of origin. Less striking, but not less fundamental, advances have been made by the chemical analysis of rocks, and by experiments in which attempts have been made to reproduce, on a small and simple scale, conditions of temperature and pressure under which minerals and rocks have been brought into being in Pluto's laboratories and workshops.

13

PLUTO'S PORTALS

AT the mention of the word volcano a picture of Vesuvius rises before the mind's eye; and well it may for, throughout the Christian era, it has carried on its awe-inspiring activities in the midst of both ancient and modern civilizations. Nevertheless before the opening of that era the real nature of Vesuvius was not even suspected, and its slopes were clothed with peaceful woods, with wild vines and cultivated vineyards. In the year A.D. 79 the slumbering underground forces began to awaken and subterranean explosions took place which produced earthquakes at the surface. Pliny the Elder set out to investigate, but never returned, for suddenly a gigantic explosion took place. To his son, Pliny the Younger, we owe an

account of those events – the first description of volcanic activity. Precisely what happened then is best described and explained in terms of subsequent observations. From that time until the present Vesuvius has been intermittently active; quiescent for a while, then bursting into activity. Ten times has that cycle been repeated since that first great catastrophic outburst.

Seen from a distance, the modern volcano is like a conical mountain with a truncated summit and steeply sloping sides. Within the summit is a basin-like hollow, the crater, from which rise clouds of steam which drift away with the prevailing wind. The flanks of the mountain are coloured black and grey. The black areas mark lava flows that are now cold. Their surfaces are rough and fissured and covered with numerous loose clinker-like fragments of lava called scoriae. These and the lava consist of a fine-grained rock called basalt which, in this case, is full of small bubbles or vesicles, like spongy bread. The grey areas are cloaks of volcanic débris varying in texture from impalpable dust through every degree of coarseness up to agglomerate, which contains scoriae and fragments of rock torn from the foundations upon which the volcano stands and shot forth from its crater.

A laboratory has been established on the slopes of the volcano for the purpose of studying its behaviour, and possibly discovering means of forecasting the approach of more serious outbursts or even of avoiding disaster. The two vigorous eruptions in recent times took place in 1872 and 1905–6. After the preliminary quakes and tremblings a fissure appeared in the upper part of the cone from which molten lava flowed. This came from a tall column of lava flowing up a pipe-like channel in the centre of the cone. Under the pressure, exerted by this column of heavy liquid, other fissures appeared and new streams of lava issued forth, giving off large volumes of steam and of gases such as carbon dioxide and sulphur dioxide. These vapours and gases must have been dissolved in the lava, under great pressure, while it was deep down in the ground. When the lava was rising to the top of the pipe the pressure naturally diminished, the steam and gases formed multitudes

of bubbles in the liquid, which frothed up — in much the same way that mineral water does when the stopper of the bottle is removed.

Much of the steam and gas fails to escape, but remains locked in the lava, and the bubbles they form give to it a spongy appearance. The surface of the lava stream soon cools and solidifies into a crust, but the inside remains liquid and continues to creep down the slope, thus causing the crust to crack and break up into scoriae.

An ordinary lava flow, 5 miles long and ½ mile wide, represents a very large weight which has been removed from the pipe of the volcano and a corresponding reduction of pressure takes

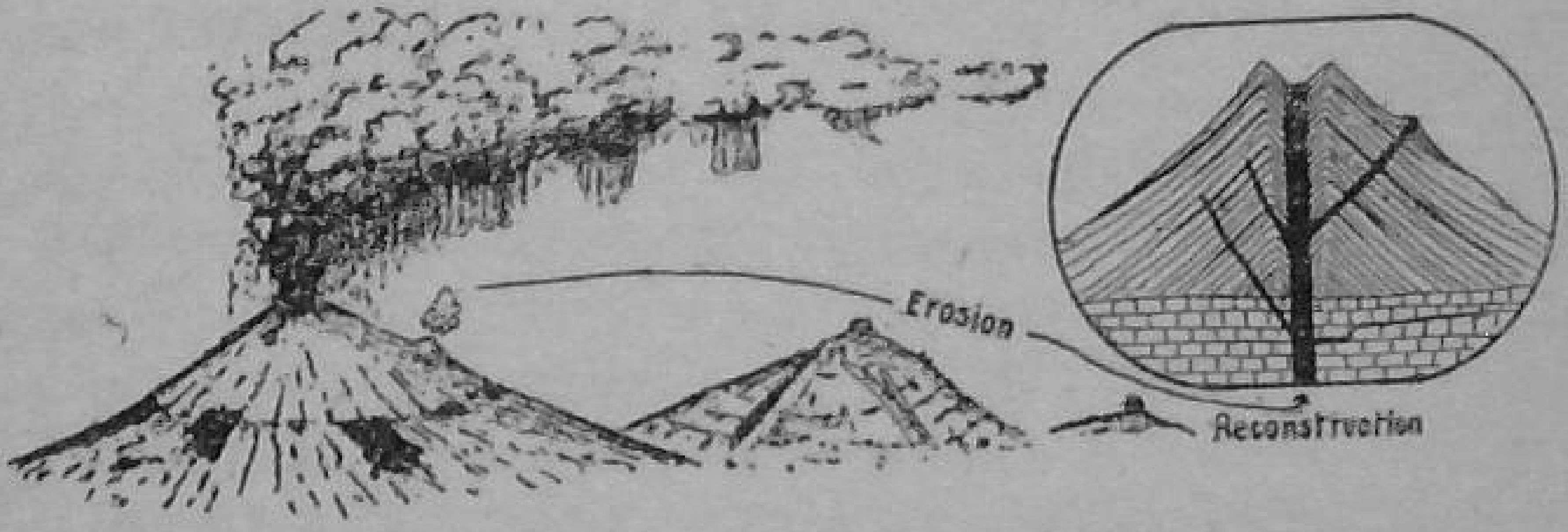

FIG. 9. THE STRUCTURE OF A VOLCANO

In the foreground is a live volcano, behind are two stages in its destruction and a diagram showing the structure inferred from these. Black = lava filling the pipe or vent, sills and dikes

place within the pipe. As the result of this, the gases still enclosed in the pipe may expand so rapidly as to produce a violent explosion which shatters and pulverizes the lava at the top of the column, and blows the dust and fragments high up into the air forming a dark dusty cloud. The volumes of steam released show as a much larger and more extensive cloud producing heavy downpours of rain. This descending through the dust turns into rivers of mud that run rapidly down the mountain slopes, becoming an even greater menace than the much slower lava flows.

The dust not caught by the rain eventually settles on the slopes or is carried farther afield by the wind, and covers the surrounding country. It was during the disastrous eruption of

A.D. 79 that Pompeii was overwhelmed by hot dust and ashes and Herculaneum was engulfed in hot mud.

Vesuvius has had a recorded lifetime of nineteen centuries, but the semicircular ridge, called Monte Somma, which partially encloses its base, provides evidence that it had existed for long ages before the Christian era. Far back in prehistoric times it must have been much more imposing than it is now, but it experienced one or several titanic explosions that dwarfed any that have been witnessed in later times; for Monte Somma is all that remains to tell the story.

Like thousands of other volcanoes that have existed before, Vesuvius will eventually become extinct. The process of building up will cease. The time for its dissolution will have arrived. Rain, frost, wind, running water will skim its surface away layer by layer and bring into view its internal structure. No one can live long enough to follow these processes through to the end or make a cinematographic record for projection on a screen. Nevertheless still-life pictures of every stage in the dissolution of volcanoes are to be found scattered about on the landscape. Hundreds of extinct volcanoes are known, each of which shows a slightly different stage in the process of destruction. From a careful examination of these a composite, but very complete, picture has been made of the internal make-up of a typical volcano. This shows that its cone is built up, from start to finish, of successive mantles of lava and dust, of scoriae large and small and of other fragmentary débris. As the coarsest débris falls near the crater and many of the streams of mud or lava do not reach the bottom of the slopes, the volcano is built up more rapidly at the centre than at the circumference, and consequently assumes a conical form. The apex of this cone is, however, always truncated and occupied by a crater, within which the layers of débris slope inwards, towards the centre. The axis of the cone is made up of a tall almost cylindrical column of solid rock formed from the lava which once flowed up the pipe. The top of this is often buried under an agglomerated mass of all kinds of volcanic débris.

Vertical walls of lava radiate outwards from the central pipe.

These represent fissures which were produced by the great pressure of the tall column of heavy liquid lava upon the cone around. Into these the lava flowed. Sometimes when a fissure broke through to the surface the lava escaped and became a lava flow. Occasionally it gave rise to a miniature volcano on the flanks of the main one. Examples of such 'parasitic cones' are seen on the flanks of Mt Etna, in Sicily.

In due time even the greatest of volcanoes may be razed to the ground, but the destructive processes still go on working, removing the rocky foundations upon which it originally stood, and exposing the sources whence it drew its strength and its supplies. The story told by these further exposures must, however, be postponed, for much still remains to be said about living volcanoes.

Hitherto we have looked at Vesuvius in its two extreme moods of complete quiescence and of catastrophic activity. But it also exhibits other moods between these. Sometimes it merely simmers. The surface of the lava in the crater cools to form a thin scum. Under this the bubbles may accumulate, like the bubble in a porridge pot. The scum swells up here and there, the enlarged bubble bursts, sends out a puff of steam and gas, and flicks lumps of lava into the air. The strength of these explosions is insufficient to send the fragments beyond the crater and they merely fall back again. At night the red-hot lava lights up the cloud of steam that hangs over the crater. This mood, which is only occasionally exhibited by Vesuvius, is perpetual in the case of Stromboli in the Lipari Islands which, because of its luminous cloud, is known as the lighthouse of the Mediterranean.

Not all volcanoes are so violent and uproarious as Vesuvius. Mauna Loa, which occupies the highest point in the Island of Hawaii, is an example of the 'non-explosive' type of volcano. Its 'crater' is two miles long and one mile wide, surrounded by cliffs more than 700 feet high. On its floor are deep pits occupied by lakes of lava in constant turmoil. The lava is so mobile that bubbles rising to its surface spurt it up in fountains. From time to time lava escapes from rents in the mountainside and, being very liquid, flows rapidly down the slopes until it

reaches the sea cliffs, over which it pours like a sluggish waterfall. Because of the extreme fluidity of the lava no scoriae or other fragmentary products are formed. The volcano is, therefore, built up of lava flows only and is consequently shaped like a dome. The whole island has in fact been built up in this way from the floor of the sea, where its base has a diameter of 70 miles. Its summit has an altitude of 30,000 feet from the sea floor, of which 14,000 feet lie above sea-level. The difference in fluidity between the lavas of these two types of volcano is largely due to their chemical composition. The viscous lavas of Vesuvius are richer in silicates than those of Hawaii.

The lavas which are extruded on the flanks of Mauna Loa leave behind them underground cavities which collapse from time to time. It is as the result of a succession of subsidences produced in this way that the 'crater' of Mauna Loa is so very extensive. The technical term for such 'craters' is caldera. The crater lake of Oregon is a good example of a caldera. Before the Ice Age, the site of this lake was occupied by a volcano 12,000 feet high. Large volumes of lava were extruded. This process so effectively undermined the mountain that it completely subsided and a caldera 6 miles in diameter was formed and became filled with water. A renewal of volcanic activity has produced another, but smaller, cone, the top of which stands up above the surface of the lake as Lizard Island.

In all the types of volcano so far considered the lava ascends to the surface through a pipe. There have been, however, many times in the past eruptions of a quite different type, one of which took place in Iceland in the summer of 1783, when a fissure 20 miles long appeared in the ground. Up this red-hot lava welled and flooded 218 square miles of country and destroyed many villages with great loss of life. As the vigour of the eruption declined activity became localized at a number of points along the fissure. It became explosive in character and consequently a series of small cones came into being.

During the last 20 million years thousands of volcanoes have been active in many parts of the world, and have left behind them cones which as yet are only partially destroyed. Nearly 500 are still active. The positions of the latter have been marked

upon a world map in the hopes that further light might be thrown upon the causes of such activity. From this it has been shown that, as with earthquakes, there is a close relationship between the distribution of volcanoes and that of mountain systems. They are not, however, uniformly scattered along these belts but are numerous in some parts and scanty in others. They are particularly concentrated in the Philippines and Japan; and to a lesser degree in Sumatra and Java. In Canada and the Western States there is only one, but from Mexico southwards they are relatively common.

Nothwithstanding the general similarity in the distribution of earthquakes and volcanoes, the precise lines along which they lie are separated from one another by distances varying up to 200 miles. While earthquakes are most frequent along the edge of the continental shelf, and are associated with the steep descent from the mountains to the ocean deeps, the volcanoes tend to lie near the other margin of the mountain belts and away from the actual zones of intense folding and thrusting. This is well illustrated by the presence of volcanoes along the margins of those median basins which form the plateaux of Persia and Asia Minor, the plains of Hungary, and the submerged basin of the western Mediterranean.

Though fissure eruptions have been so rare during the period of recorded history, they have often been active on a mighty scale during geological time. The fissure eruption in Iceland illustrates, but is not directly linked with, a long succession of similar outpourings which in Tertiary times flooded the belt of the earth's surface which now stretches from Greenland through Iceland, the Faroe Islands, and the Inner Hebrides to Antrim covering an area of 600,000 square miles. In any of these places lava flows, varying in thickness up to 60 or even 100 feet, are seen lying one upon another; and are estimated to have a total thickness at some points of 1500 feet. These out-pourings did not succeed one another in rapid succession. Quite often the surface of a flow was exposed to the action of weathering agencies so long that a rich soil was formed, which became covered with vegetation. Soil of this kind, charred wood, and thick deposits of lignite are occasionally

found between the lava flows. Some of the thicker lavas exhibit that fascinating columnar structure, so well seen in the Giant's Causeway. In one of the islands of the Inner Hebrides, the Isle of Staffa, the sea has excavated a wonderful cave out of these columns. According to legend this was inhabited by the Giant Fingal. Some understanding of the way in which these columns were formed may be gained by watching the formation of sun cracks in mud. As the surface of a sheet of mud dries it shrinks and cracks are formed. They generally appear in set of three, radiating from one point. As the cracks extend they eventually intersect those from other points. In this way the surface of the mud is divided up into a mosaic of plates which are frequently, but not always, six-sided. So also the deeper portions of a thick lava flow cool slowly and uniformly. As it shrinks cracks are formed in the same regular way. These cracks, however, extend through many feet of solidified lava and instead of forming plates form columns, with a number of sides. The most frequent number is six. Each column also shrinks vertically and is consequently divided at intervals by transverse cracks or joints. The upper part of the flow cools more quickly and shrinks less uniformly, with the result that the columns are irregularly shaped like pieces of starch.

In Antrim the lavas were poured out over a landscape of chalk downs. In some of the sea cliffs the black basalt lavas are seen lying upon the chalk. Here and there in these cliffs vertical walls or 'dikes' of basalt penetrate the chalk from below, and sometimes pass into the overlying basalt. These represent the original fissures up which the lava welled. In parts of Scotland where the covering of basalt has been weathered away multitudes of these dikes are seen traversing the countryside for many miles. The contemplation of these swarms of dikes fills the mind with fearsome pictures of the hell which once broke out over such peaceful landscapes. Here in these scattered islands off the west of Scotland only fragments of the once fiery floods remain. Large areas, broken by earth fractures, have sunk below sea-level.

In other parts of the world similar mighty molten deluges were poured forth. In the north-western corner of the United

States, in Oregon, Idaho, and Washington lavas cover 200,000 square miles of country. Similar scenes were enacted at other times in the far distant past in the Deccan, India; the rift valley region of Central Africa; the Parana Plateau of South America; and elsewhere. There is, however, a quite different side to this lurid picture, for the surface of these basalt rocks, when exposed to the destructive action of weathering agents, produces very fertile soils.

The continued uncovering of countrysides, penetrated by such basalt dikes, has brought to light the existence of what may be described as subterranean flows, in the form of sheets of lava injected between the layers of sedimentary rocks. These have consolidated into basalt or some kindred type of rock. Such underground sheets are called *sills*. A famous example is the Whin Sill in the north of England which was injected into the carboniferous limestone. It has a maximum thickness of 240 feet and extends about 80 miles from south to north. Another famous example forms the feature near New York known as the Palisades. Its outcrop extends along the west bank of the Hudson River for a distance of 50 miles and, at some points, is 1000 feet thick.

A sill may at first sight be mistaken for a lava flow, buried under rocks formed after it was poured forth. A lava flow, however, only bakes the rocks over which it has flowed, but a sill bakes the rock above as well as below. Moreover scoriae and other products of eruptive activity are usually found associated with a lava, but are absent from a sill.

Even in regions where the wearing away of the rocks has been carried down to profound depths the sources from whence the dikes have drawn their supplies of liquid rock have never been exposed. It seems most natural to assume that they have come up from the still more deeply situated reservoirs of basalt upon which the continental platforms rest. At such depth the temperature is no doubt high enough to melt the basalt but, normally, the pressure is so great that liquefaction may not actually take place. In some circumstances, however, the vertical pressure may be reduced sufficiently to allow melting as, for example, at times and places where the crust of the earth

is being stretched. Then a swarm of faults and fissures may appear up which the lava wells and either floods the surface or is injected along the bedding planes as sills. Occasionally less extensive but much thicker lens-shaped injections, known as laccolites, are formed. Owing to their greater mass the magma in these cools more slowly and produces more coarsely grained rocks such as dolerite or even gabbro. The Cuillin Hills in the Island of Skye have been carved out of a laccolite of gabbro.

When the volcanoes of an area become quiescent or even extinct, steam and gases continue to escape through holes and fissures in the ground, known as fumaroles or solfataras. Fumes of sulphur, boric acid, or various chlorides crystallize on the sides and around the apertures of these passageways, and provide useful sources for the supply of these materials to commerce. With a further decline of volcanicity these emissions of vapours and gases diminish until only carbon dioxide is released. The Death Valley in the great basin region of North America is said to owe its evil name and reputation to the presence of outlets of this gas which, because it is heavier than air, lingers along the floor of the valley.

This brief account of the volcanoes of the world would be incomplete without a reference to those striking features known as hot springs which are so often associated with them. Some of these behave like normal springs and issue from the ground in a stream of warm or even hot water, as, for example, in the Mammoth Hotspring of Yellowstone Park and similar springs in New Zealand and Japan. The waters in these cases contain much siliceous material in solution. As the water flows down the slopes it cools and deposits this silica in the form of a series of basins or of terraces of great beauty. In other cases the water issues forth in a much more striking fashion for it is ejected forcibly up into the air as a hot steaming fountain or geyser.

Much of the water is of meteoric origin. That is to say it has fallen as rain and, soaking into the ground, has filled the cracks and cavities in the rocks. A small portion of it is 'juvenile' water, which has escaped from subterranean magmas for the first time. Its presence accounts for some of the peculiar con-

stituents contained in the hot spring. At the great depth to which the water descends the temperature may be twice as high as that of boiling point at the surface. It does not, however, boil, because it is prevented from doing so by the pressure of the water above. Eventually some of the superheated water becomes so hot that it overcomes the pressure and is at last converted into steam. This is, of course, of much greater volume than the water from which it was formed, and so it pushes the water above it up until some of it overflows on to the surface of the ground. This automatically reduces the pressure on the remainder of the superheated water, which rapidly changes into still greater volumes of steam and ejects all the water above it with such explosive force that it rises as a fountain, hundreds of feet into the air.

14

PLUTO'S LABORATORY

To a novice a chemical laboratory is a silent wonderland of shining glass apparatus and of bottles, filled with strange and unfamiliar substances, labelled with jaw-breaking names. On the benches are groups of bottles filled with more frequently used reagents – acids and alkalis, which change the colour of litmus paper to red and blue respectively – and other substances which are neutral.

Pluto's laboratory presents a striking contrast. When the earth was merely a mass of vapours and gases, when it cooled to a liquid state, this variety of substances, extracted and christened by chemists, did not exist; but the materials for making them were there in the form of electrons, and atoms moving about freely between one another. The outflows of lava described above indicate that deep down in the earth to-day some of this primeval liquid or its equivalent still exists. The geologist calls it *magma*, and one of his main aims is to discover the steps by which that homogeneous fluid has given rise to the marvellous diversity of minerals and rocks, useful ores and

precious gems which, exhibited in a museum, make it a rival of an art gallery as a place for the contemplation of beauty. He cannot start at the magma end of the story and so he has to be content to work backwards from these final products, which he has sorted out and arranged in his museum.

One striking fact he soon discovers is that the familiar acids of the chemist's laboratory play a very insignificant part in the earth's crust. Indeed the most abundant acid in the rocks is *silica*, a substance formed by the union of silicon with oxygen. In recent years silica has been made familiar in every household by the manufacturers of Pyrex plates and dishes consisting of silica glass. Silica is a strange acid, for it is solid, has no taste, and produces no effect on litmus paper. The fact that it is used for such utensils shows that even man can heat it up to temperatures that are high enough to melt it. But he can do more than that. By mixing it with carbon, or charcoal in a pure form, and heating the mixture in an electric furnace he produces carborundum, a very hard substance now extensively used for making hones and grindstones. Evidently at high temperatures silica becomes an active agent.

Estimates based upon the chemical analysis of many kinds of rock from all parts of the world shows that no less than 59 per cent of the earth's crust consists of silica. Most of this is combined with sundry alkalis and oxides to form various minerals; but some of it remains free. It then assumes many attractive forms including beautiful crystals. When these are glass clear they are called quartz. Sometimes they are coloured and are given different names: milky quartz is white; rose quartz is pink; smoky quartz, dark brown; cairngorm, light brown; amethyst, purple. Very minute crystals, invisible to the naked eye, massed together form chalcedony. This is deposited in successive layers of different colour as in agate and onyx, sard and carnelian. In a non-crystalline or amorphous form it is known as opal. Sandstones consist largely of small grains of quartz.

The substances with which silica has been combined to produce the commonest minerals in the rocks are remarkably few in number. They are all oxides, either of silicon or of one of

six metals, the commonest of which is aluminium, which, united with oxygen, is known as alumina. This oxide makes up slightly more than 15 per cent of the earth's crust. It occurs in the rocks as corundum; a very hard mineral which, before carborundum was invented, was used for the same purposes under the name emery. In special circumstances it occurs as the exquisite gemstones ruby and sapphire.

The metal iron has been used by man, during the last twenty-five centuries, for a multitude of purposes. Its chief drawback has been that it so readily units with oxygen to form iron oxide or rust. Though much less abundant than aluminium it exerts a very widespread influence. The slightest trace of iron in the sands, which are used in the manufacture of glass, will give to the whole output a green colour. In fact it is a universal colouring agent. Bricks, blood, leaves, paint powders, clays, shales all owe their colour to some compound of iron.

Calcium approaches iron in abundance but is a much less familiar metal, for it oxidizes much more rapidly on exposure to air. The oxide is called lime. Of the three other metals to be mentioned magnesium alone is commonly seen. It is produced commercially as a ribbon or a powder which lights easily and burns with an intensely bright flame. The white powder produced by the burning is magnesium oxide. The metal sodium provides one of the earliest thrills for the juvenile chemist. It is so soft that it is easily cut with a knife and it is so light that it floats on water. Potassium is very similar, but is not quite so easily isolated. Both oxidize so rapidly that they are shielded from contact with air by being kept in paraffin. The last two oxides are strongly alkaline.

The oxides just described together make up 96 per cent of the earth's crust in the following proportions:

Oxide	*Percentage*	*Oxide*	*Percentage*
Silica	59·07	Soda	3·71
Alumina	15·22	Potash	3·11
Iron oxides	6·81	Magnesia	3·45
Lime	5·10	Other oxides	3·53
			100·00

The other metals include such elements as gold, silver, uranium, titanium, tungsten. Though very rare they have properties of great value to mankind. Like the cook's proverbial pinch of salt, a little goes a long way. For instance, a trace of tungsten in steel prevents it from rusting. A speck of iridium on the point of a fountain-pen nib prolongs its life.

In Pluto's laboratory these materials, which now make up the rocks and minerals of the earth's crust, together with the constituents of those gases and vapours which play such a conspicuous part in a volcanic eruption, were mixed with one another in that hot solution referred to earlier as magma. Clues to the stages in the conversion of magma into rock may be picked up by making a careful examination of hand specimens and thin slices of the rock.

Take for example a piece of granite. It will be seen that it is made up of crystals and fragments of crystals. Some of these are transparent and glassy; these are quartz. Others are cloudy and coloured white or pink; these are felspar, and consist of silicates of alumina and one or other of the alkaline oxides. Quite often the felspars show the straight boundaries of nicely shaped crystals, while the quartz merely fills in the space around them. From this it is inferred that the felspar crystallized out of the magna before the quartz. Much less common is the mineral mica. Its crystals are usually nicely formed and may be enclosed in both the felspar and the quartz, and it must have been formed before either of the two had finished crystallizing. Examined under the microscope many of the mica crystals are seen to enclose small crystals of zircon; a bright, hard mineral familiar, to those who are fond of jewellery, as an attractive gem stone. Such facts as these create in the geologist's mind a picture of the magma cooling slowly. As it does so some of the atoms of zirconium, moving about in this complex solution, unite with atoms of silicon and oxygen to form minute crystals situated at points here and there. These little zircons grow and increase in size as other atoms diffuse towards them from the surrounding solution. While the temperature continues to decline, other more complex crystalline groupings of atoms begin to form at various points. These include silicon, alumin-

ium, potassium, oxygen, and hydrogen, sometimes also magnesium and iron; and give rise to mica crystals, which may grow round and enclose the zircons that happen to be floating about within reach. Later, scattered nuclei of felspar appear, grow, and may enclose mica crystals that happen to lie in the path of their growth. Eventually the quartz appears and does the best it can in the space that has not been occupied.

Under the microscope the quartz often exhibits a peculiar type of enclosure known as a 'liquid cavity', usually quite irregular in shape. The fact that it contains liquid is proved by the presence of a bubble which moves about as the slice is turned round. Careful investigation has shown that sometimes the liquid is carbon dioxide. Quite often the cavity also contains minute cubical crystals of salt. These facts remind us that the magma contains in solution the constituents of the various vapours and gases that are emitted in such large volumes during a volcanic eruption. Even the bubble provides food for thought. It is not an original feature in the rock, but has appeared because of the contraction of the liquid as the temperature declined. Estimates based upon the relative volumes of bubble and fluid indicate that the original temperature was not higher than 700°C which is a little lower than that of liquid lava.

Much work has been done in laboratories on the melting and mixing of minerals at high temperatures, and on the effects of slow or of rapid cooling. This has been a great help in understanding the processes and changes which take place in magmas. Nevertheless it must be borne in mind that in addition to a magma being vastly more complex than any solution that the experimenter can produce, the pressures are also much greater than any available to him.

As illustrating the benefits derived from such observations and experiments reference may be made to a few of the results of such work done upon felspars. These are divided into two major groups differing in chemical composition. The orthoclase felspars contain potash. The plagioclases contain lime and soda. The latter form a graded series differing in the relative proportions of soda and lime. At one end of the series is albite in which soda is dominant. At the other is anorthite in which

lime is dominant. Varying mixtures of these two account for the other members of the series. All are relatively easily distinguished under the microscope by their optical and other properties. Sometimes a plagioclase has what is described as a zonal structure. That is to say the core of the crystal consists of anorthite (lime felspar) and the outside of albite (soda felspar). In the successive layers, from the centre outwards, the amount of lime decreases and soda increases. The contemplation of such a crystal creates a vivid mental picture of certain chemical changes which took place in the magma as it cooled and the crystal grew. At an early stage the atoms of calcium were linked on to those of silicon, aluminium, and oxygen, and began to crystallize out as anorthite. Then a few sodium atoms joined forces and helped to form a lime-soda zone around the anorthite. As the amount of calcium in the magma diminished, the quantity of sodium that entered into the compact increased, and a soda-lime felspar zone was added to the crystal. Eventually an almost pure soda felspar formed the outermost coat.

In his most detailed studies of the minute structure of igneous rocks the geologist comes upon the tracks of various other processes which took place during the cooling and consolidation of magma. To consider these would convert these few chapters into a thick volume on Petrology; enough, however, has been said to illustrate the technique by means of which geologists are gradually spelling out the story of the chemical and physical changes which take place when magmas become rocks.

15

PLUTO'S BASALT FACTORY

ATTENTION has already been directed to the fact that two of the most abundant rocks at the earth's surface are basalt and granite. The former is dark, heavy, and finely grained. The latter is coarsely grained and light, both in colour and weight. A cursory inspection of any collection of igneous rocks in a

museum shows that there are a multitude of other types besides these two. The specimens in the show cases are all practically the same size and docketed with labels uniform in size and style of print. All this creates the unconscious, but false impression that they are all relatively abundant. A much truer impression would be made if the curator put on show two large blocks, one of granite and the other of basalt, a ton or so in weight, some distance apart upon the floor, and filled up the spaces between them and around them with small hand specimens and chips of the other rocks.

Confronted with this multitude of different rocks, the geologist is faced with a similar problem to that facing the head of a large business who receives by every post numbers of letters, bills, receipts, orders, and complaints. All these have to be sorted out and filed under appropriate headings so that all correspondence relating to the same matter may be speedily found. So the geologist, before he puts his specimens away in sets of drawers, must discover the best principles upon which to arrange them; so that those having the same history, and are most nearly related, are put away close together.

Every igneous rock is a manufactured article made in Pluto's factory out of crystals and minerals and non-crystalline glass. The most obvious feature that strikes the eye when looking at hand specimens is the difference in texture. At one extreme are the coarsely grained rocks, like granite, in which the crystals are large and easily distinguished from one another. At the other extreme is obsidian which looks like a lump of very dark bottle glass. It is difficult to realize that these two rocks, when chemically analysed, are found to have practically the same composition. The remarkable difference between them is due mainly to the conditions under which they cooled and consolidated. Obsidian is found in lava flows in Iceland, New Zealand, and elsewhere. Thus exposed to the air the magma lost its heat rapidly and solidified too quickly to allow the atoms of silicon, aluminium, and other elements to congregate and form minerals and crystals. It set, therefore, in a non-crystalline or glassy state. Granite, on the other hand is found in situations which prove that the original magma, from which it was manufactured,

remained deeply buried in the crust of the earth. Thus protected it lost its heat very slowly. The atoms of the various elements it contained had time to come together and form centres of crystallization, towards which kindred atoms travelled or diffused through the magma from all directions. Thus crystals grew to quite large sizes. Sometimes the magma moved, before the process was complete, to higher levels nearer the surface. There it cooled more quickly, and a crop of smaller crystals grew between the large ones. The latter are often referred to as porphyritic crystals and the rock as a porphyritic rock. This general relationship between the depth at which a rock consolidates and the texture it shows was recognized at an early date and furnished one of the first principles adopted in arranging the specimens. These were put into three groups: the plutonic group for those from profound depths, the intrusive group for those found nearer the surface, the extrusive group for those which were poured out on to the surface. In course of time, however, it was found the two latter overlapped to such an extent that the attempt to separate them in the museum frequently failed. Thus, for example, the margin of an intrusion, in contact with relatively cold rock, cooled so rapidly that it became a glass. On the other hand the centre of a very thick lava flow cooled so slowly that a moderately coarse rock was the result. This distinction between intrusive and extrusive rocks was less emphasized for the purposes of indoor arrangement. For the field geologist, however, it still has its uses.

With the passage of time it was realized that the chemical composition of rocks provided a much sounder basis for grouping them. Thus, for example, 70 per cent of the substance of granite may be silica, but basalt contains only about 50 per cent. The analyses of many rocks shows that the amount of silica present ranges from as much as 80 per cent down to as low as 30 per cent. It has, therefore, proved convenient to group rocks according to the amount of silica they contain under the following headings:

Acid Rocks with more than 66 per cent of silica.
Intermediate Rocks with between 66 and 52 per cent of silica.
Basic Rocks with less than 52 per cent of silica.

Each of these groups naturally contained so many rocks that further sub-division became necessary. Attention was, therefore, turned to the various oxides and bases with which silica combined. Chief among these were potash, soda, and lime. Analysis revealed an interesting serial change in the relationship of the two former to the last in each of the three groups. In some rocks the soda and potash were dominant. In others the amount of these decreased and the lime increased until the lime was dominant. This discovery made it possible to sub-divide each of the three main groups into Alkali, Transitional (Monzonite), and Calcalkali groups respectively.

In the geologist's filing cabinet there are about eighteen drawers to hold rock specimens arranged upon a chemical basis. Unfortunately it takes a long time to analyse a rock. The geologist in the field may find different types of rocks which he must be able to identify at least roughly if he wishes to carry on his further explorations intelligently. On the other hand his colleague, in the laboratory, may receive scores of specimens which must be arranged quickly, if he does not want to be buried under the additional collections which may soon descend upon him. He cannot wait for the chemist, he must have a more rapid means of deciding where to place his material. Fortunately the minerals that can be seen with the naked eye in hand specimens, and with the microscope in thin slices, reflect quite closely the chemical composition of the rock. Thus for example if the original magma contained more silica than was required to combine with the oxides and bases that were present in the solution, then the excess of silica crystallized out as quartz. The presence of quartz may, therefore, be generally taken as a sign that the rock contains a high percentage of silica, that in fact it is an acid rock and should be placed in one of the 'acid' drawers of his cabinet. If it is also coarse grained, it may go with the acid plutonics. He then turns his attention to the felspars. Are these mainly orthoclase with perhaps some albite? Then the rock specimen may go into the tier for acid rocks with alkali felspars. Thus it comes about that from a miscellaneous assortment of specimens those that are closely related are placed in proximity to one another. With his

material thus systematically arranged the geologist can, with greater confidence, carry on his enquiries into the ways in which rocks have been made and arranged in nature. One or two examples will give a picture of the geologist's ways of working.

On the Shiant Islands, in the Hebrides of Scotland, a sill 500 feet thick is exposed to view. The magma which was injected into the country rock must have been of uniform composition. As it cooled a number of minerals crystallized out of which only olivine, augite, and plagioclase need be mentioned. Throughout the upper 400 feet of the sill the relative proportions of these minerals remained the same, thus producing a uniform rock. In the bottom 100 feet, however, these proportions changed in the way shown in the table below.

These figures taken together with features seen in the rocks themselves indicate:

(*a*) That the heavy mineral olivine began to crystallize out first and much of it sank towards the bottom of the sill while the magma was still very liquid.

(*b*) Some of the plagioclase, which is a lime felspar, crystallized out early while the magma was liquid and sank. Most of it, however, appeared when the magma had become viscous and hindered the crystals from sinking. These consequently remained in the upper layers of the sill.

TABLE SHOWING THE PROPORTIONS OF DIFFERENT MINERALS AT SUCCESSIVE LEVELS IN THE SHIANT SILL FROM ABOVE DOWNWARDS

Level	*Olivine per cent*	*Augite per cent*	*Plagioclase per cent*	*Specific gravity of the rock*
Top 400 ft	11	25	58	2·95
Next 75 ft	31	17	58	3·02
Next 15 ft	59	10	26	3·10

This example illustrates one important way in which the one magma may give rise to different assemblages of minerals and therefore to different types of rocks. In this case the bottom rock was rich in olivine and poor in augite and plagioclase.

The main mass of rock on the other hand was comparatively poor in olivine and rich in the other two minerals. The method pursued by Pluto in this case is known as 'fractional crystallization' in which the crystals of a mineral when formed were removed and accumulated in another part of the magma. Incidentally it should be noted, as shown in the specific gravity column, that the bottom rocks were heavier than the upper.

A striking example of the way in which the study of thin slices contributes to the understanding of great problems is provided by a lava from Vesuvius known as leucite basanite. In one slice of this rock two larger crystals of augite and leucite respectively were seen surrounded by small crystals many of them minute. Just as bits of straw and other débris floating on water crowd round the prow, and stream past the sides, of a boat that is moving along; so these minute crystals were crowded round one end of each of the two large crystals and looked as though they were streaming past the sides. This proved that while the rock was still liquid they were actually moving through the magma. This crowding was, however, around the lower end of the augite and the upper end of the leucite. Evidently the former was sinking, and the latter was rising or floating upwards. As the result of these contrary movements the upper part of the lava became richer in leucite and the lower richer in augite. Consequently two varieties of lava rock were produced within the same lava flow.

In face of such facts it is not surprising to learn that lava flows, issuing from the same volcano at different times, may differ from one another. Even in the case of Vesuvius the earliest lavas found in Monte Somma were richer in felspars than those which have been poured out in more recent times. Still more strange is the fact that in the little island of Vulcano in the western Mediterranean acid obsidian and basic basalt come forth from vents that are quite close to one another.

When discussing fissure eruptions earlier, reference was made to the outpouring of great volumes of basalt. In areas where the basalt has been removed the swarms of dikes, which originally fed them, are exposed. It is then found that though the majority of these 'feeders' are basic in composition, some

are andesitic, that is to say intermediate; and a few are even felsitic, or acid.

Such facts suggest that processes, similar to those which produce different types of rock in sills and lavas, are at work also on a larger scale in the deeply placed reservoirs from whence these dikes proceed. Despite extensive denudation, such reservoirs have not been brought near to the surface and uncovered. It must, therefore, be concluded that the pipes of volcanoes and the dikes which feed great floods of basalt must go down to very profound depths and may even tap the sima which underlies the continents.

Hitherto, in our tour round Pluto's realms, our attention has been mainly taken up with basalt and closely related igneous rocks. For that other very abundant rock, called granite, we must now step across to another wing of the factory.

16

PLUTO'S GRANITE FACTORY

SAND and mud – these are the commonest constituents of the sedimentary rocks. Normally the former consist mainly of quartz grains, the latter of powdered quartz and minute flaky crystals of mica and similar minerals. These make up the normal sandstones, clays, and shales. Sometimes, however, sand and mud consist of broken and powdered shells, and in the course of time become limestones.

These rocks are mainly deposited in water and, even when they are lifted up to form land, still hold quantities of water in the pores or spaces between the grains. In clays some of the water is absorbed into the minerals themselves. Though these rocks make up much of the land, only limited portions of them lie near the surface. Each layer of rock dips downwards into the ground, often to considerable depths, where they are subjected to the great pressure exerted by hundreds or even thousands of feet of rock above them. In course of time much of the water is squeezed out of them. The soft plastic clay thus

becomes converted into hard but brittle shale which when hit with a hammer breaks into flat pieces. It is not surprising therefore that among the oldest rocks shales take the place of clays.

In sandstones the grains withstand this pressure and much water is still held in the rock. In some of the very old sandstones, such as those at the base of the Cambrian, silica derived from elsewhere has been dissolved in the water and redeposited around the grains. In this way the pores have become completely filled up and the sandstone converted into a hard tough rock called quartzite.

In mountain belts where the rocks have been subjected to great lateral pressure the layers are often intensely folded. Even when this folding appears to have reached its limits the pressure continues and the flaky minerals are rearranged with their flat faces at right angles to the direction of pressure. The rock has now become a slate and splits easily into thin plates along the faces of the reoriented crystals. It is described as having a slaty cleavage and is now called slate. Slates are extensively used for roofing and various other purposes. They are widespread in most mountainous regions.

When these regions have been worn down to a considerable extent masses of granite are found penetrating the rock at their roots. In the Western Cordillera of North America remarkable examples of this occur. For instance at the heart of the Sierra Nevada one such mass is 400 miles long and 80 miles wide. Another in the Coast Range is 1100 miles long. Such great masses are called *batholiths*. Their upper surfaces are often very irregular. Their sides slope steeply down into the ground, but their bases have never been seen. It may be that some of the smaller granite masses, known as *bosses*, are merely protuberances from the tops of batholiths that have had their covering of sedimentary rocks only incompletely removed. A number of bosses are seen in the denuded mountain belts of Britain, as for example near Shap and Skiddaw in the Lake District, in Dartmoor and the other moors in the Cornwall-Devon peninsula. In all these cases the granite mass cuts across the bedding of the sedimentary rocks in a way that, from the days of Hutton, the great Scottish pioneer in Geology, until recent times, has been

taken as proof that the granite was intruded into its present position as a hot liquid or magma. Nevertheless, in accordance with the spirit of the times, such apparently well-established notions are being metamorphosed.

The rocks in the vicinity of a granite boss have usually been metamorphosed within a zone several miles wide. This is called the metamorphic aureole. If a slate is followed, as it enters the aureole, it is seen to become baked and spotted with small whitish patches. Farther inwards these are occupied by crystals of andalusite and chiastolite; so called because at the centre of each is a dark cross. Meanwhile the minute flakes of other minerals, which make up the body of the rock, recrystallize and become a matted mass of micas, intermingled with recrystallized quartz. In fact it is now a new rock known as hornfels. These changes have been brought about by the transference of heat from the granite, to some extent by conduction, but mainly by penetrating fluids.

That some interchange of material has actually taken place between the two types of rock has been proved by the careful examination of them at many places in and near the contact margin. Thus, for example, chemical analysis shows that silicate of alumina has passed into the granite from the shale. The latter has in consequence been disintegrated and its particles absorbed, or rather assimilated, by the granite. Microscopic examination confirms this, and shows the presence in the granite of such minerals as andalusite and tourmaline; which must have been formed originally in the metamorphic aureole. On the other hand the innermost zone of the aureole has been enriched with additional potash derived from the granite.

Similar and perhaps more striking facts are forthcoming from a study of other granite masses. Thus, for example, at Shap one of the rocks which has been penetrated by the granite is a lava, slightly more acid than basalt, known as andesite. Blocks of this rock have been caught up into and completely enclosed in the granite. The latter with its coarse-grained ground-mass of quartz and felspar, and its large porphyritic crystals of orthoclase, presents a striking contrast to the uniformly grey and fine-grained andesite of the lava. On looking

at the enclosed blocks of lava, however, the eye is caught by the presence of large pink crystals of orthoclase imbedded here and there in the heart of the andesite. It is inconceivable that these crystals passed intact, as crystals, from the granite through and into the solid substance of the block. As one contemplates one of these crystals in its strange surroundings two questions arise. How did the crystal get there? What has happened to the andesite that was in the space now actually occupied by the crystal? There is no sign that any of the andesite has been pushed out of place by the crystal as it grew. The only satisfactory answer is that atoms of potassium and oxygen, or molecules of potash, quietly travelled between the atoms and molecules making up the substance of the andesite. At various points they have joined forces with the silica and alumina already present in the rock and have gradually changed this into orthoclase on the spot – an illustration of the principle of 'peaceful penetration', not unlike the policy pursued by political organizations which form cells here and there within a community of a quite different political colour.

In these and like cases metamorphism has taken place along a narrow zone of country rock lying close to or in contact with the margin of a small granite mass. This is usually described as 'contact metamorphism', a phrase based upon the relative positions of the rocks. If, however, the same facts are looked at from the standpoint of the effects of heat, it is described as thermal metamorphism.

In such areas as those just considered the rocks are no older than the Palaeozoic era of 300 to 500 million years ago. In regions occupied by the much older Pre-Cambrian rocks denudation has carried the processes of uncovering to much deeper levels where metamorphic rocks may make up as much as 50 per cent of the whole. In Britain the largest area of Pre-Camberian rocks is in Scotland, north of the Midland Valley. Here in the Grampian Highlands metamorphism has taken place upon a very large or regional scale. Along the southern margin, where these highlands abut on the Valley, there lies a narrow fringe of practically unaltered rocks of clay origin. Traversing the country in a northerly direction for distances

varying from 5 to 20 miles geologists find that the rocks have been completely changed into schists. That is to say, into a type of rock which splits into thin flakes, like leaves or folia. Hence the descriptive term *foliated* for such rocks. While this schist consists mainly of mica it contains here and there, imbedded in it, well-shaped crystals of new minerals. G. Barrow showed in 1912 that the suites of minerals varied systematically as he travelled from one zone of country to another. He therefore selected a series to serve as index minerals for the successive zones from south to north. They were *biotite*, *garnet*, *staurolite*, *kyanite*, and *sillimanite*. Later workers, adopting his method, have traced and mapped similar zones across Scotland from shore to shore. It has also been used with success in mapping the metamorphic rocks in areas in other parts of the world, as for example, in Duchess County, New York.

Mica schists are not the only ones that are found. Schistose structure may be imposed also upon lavas and other igneous rocks which contain minerals, like hornblende, tremolite, and chlorite, that can become flaky or foliated. Some minerals, including quartz, felspar, and calcite, always retain a more or less granular condition. When, for instance, a sandstone is metamorphosed its quartz grains merely recrystallize and become closely packed against one another like a microscopic mosaic pavement. The rock is then called a quartzite, and is identical in general appearance and toughness with the one already described under that name.

Limestones are also present in these areas and have been subjected to the action of metamorphic processes. In ordinary limestone quarries large quantities of the rock are stacked in kilns and burnt at a white heat. At such high temperature the carbon dioxide in the limestone is driven off and 'burnt' lime, or calcium oxide, is left behind. This is used for making mortar and liming soil. A century and a half ago (1805) Sir James Hall filled a tube with a powdered limestone known as chalk. He then sealed the tube hermetically so that no carbon dioxide could escape and heated it to a high temperature. At the close of his experiment he found that the rock had been changed into marble. This demonstrated the conditions under

which, in nature, great masses of limestone have been converted to marble in regions where metamorphic processes have been at work. When marble is examined under the microscope it is seen that the limestone, including any fossils it contains, has been converted into a granular mosaic of calcite crystal. The white marble, which is so effectively used by sculptors for carving statuary, was metamorphosed from the purest limestones. Many limestones, however, contain some clay or sand. These impurities have usually been converted into crystals of garnet, lime felspar, or other similar minerals.

One type of rock which abounds in areas where metamorphism has taken place on a regional scale is *gneiss*. Both on a large scale in the field and on a minute scale, in hand specimens and slices, this rock, like schist, also shows foliation. Gneiss, however, has a much coarser texture. In it the folia show as dark and light streaks or bands. The dark are largely made up of dark-coloured minerals such as hornblende or black mica. The crystals lie with their long axes in one general direction, thus producing the impression of flowlines following the boundaries of the lighter by much more irregular bands. The light bands are made up of quartz and felspar crystals. These are more stumpy in form and tend to be grouped in elongated lenticles, the attenuated margins of which consist of smaller pieces of the same minerals.

It will be noticed that this gneiss contains the same assemblage of minerals as granite. Indeed there are some granites in which there is a marked tendency towards a linear, as opposed to a scattered arrangement of the minerals. They look as though they had been squeezed when they were in a plastic state, or had flowed when in a fluid state. These are described as gneissose granites.

This reference to gneissose granite brings up the question of the origin of granites. For a long time the widely accepted view has been that they are igneous rocks. That is to say rocks that have consolidated from a liquid state or a magma. Many observations certainly support that view. The Scottish pioneer who put it forward, in the eighteenth century, noted that the sedimentary rocks in the close vicinity of a granite mass were

often baked as though by heat. He also referred to instances where a fine-grained granite, known as granodiorite, occurred in veins running through adjoining rock as though they had been injected while still liquid. A number of facts, since discovered, fit in with that view. There are, however, many others which indicate that the events which led up to granite occupying its present position were sometimes much more complex.

One curious feature about these masses, both great and small, is that the rocks around them do not seem to have been disturbed or pushed aside to make room for such bulky intruders. That being the case, what has happened to the rock that was in the place where the intruder now sits? The frequent presence of blocks of the original rock imbedded in the granite suggests that the rocks, as they were being intruded by magma, broke away piecemeal and, foundering into this red-hot sea, were either dissolved or sank to the bottom. While that may have happened in some cases there are many field observations which indicate a wider and more complicated solution of the difficulty. These have been made in many widely separated areas in different parts of the world. One outstanding example must suffice.

Reference has already been made to the mighty batholith in the heart of the Sierra Nevada mountains in the Western States. Near its Californian margin the main rock in the mass is a light-coloured biotite granite which has evidently consolidated from a magma. Between this and the surrounding schists and sedimentary rocks a dark-grey granite intervenes. This varies greatly in texture and composition, and encloses many porphyritic crystals together with numerous pieces of the country rock. One exposure, a mile long, seen in the sides of a gorge in Inyo Range is very illuminating. Here the schists contain many large crystals of orthoclase felspar. Their presence can only be accounted for by assuming that emanations from the granite magma penetrated into the schist, bringing with them atoms and molecules which, by combining with substance of the schist, formed silicates of alumina and potash; and thus built up the orthoclase felspars in spaces previously occupied

by schist. Farther along the side of the gorge quartz and felspar, formed in the same way, appear more abundantly as wavy streamers between the folia of the schist. Beyond that streamers become so extended that only wisps of schist and porphyritic orthoclase crystals are left enveloped in granite. Finally these wisps also disappear and the rock merges into the darker granite. This striking series of gradual and progressive changes leaves no doubt that the darker granite was not formed by consolidation of an intruding magma, but from the surrounding country rock by chemical action of energetic fluids emanating from the magma of the lighter-coloured granite. This process is called granitization and the mixed rocks, found in the zone where these great changes take place, are called *migmatites*.

Some investigators suggest that possibly all granites, including even the greatest batholiths have had a like origin. The fact that they are situated in the cores of great mountain systems gives a clue to the way in which this could have taken place. We have already seen that these systems arise on the sites of pre-existing geosynclines, in which sediments had been accumulating for long ages and attained profound depths; so profound, indeed, that they came within the sphere of action of granitizing emanations given out by the primal magma of the earth. These, reacting with the mineral constituents of the sediments, produced new compounds which crystallized out as hornblende or mica, as soda and potash felspars, and as quartz. In other words they produced great masses of granite, now called batholiths, without necessarily passing through the liquid phase known as magma. If that be so, should granite be called an igneous rock? Yes and no: for sometimes the temperature and pressure were such that the rock liquefied. In any case the vast multitude of observations, typified by the one just described in outline, show that gneisses, schists, and migmatite should be classed with granites as rocks of deep-seated or plutonic origins; as opposed to the superficial volcanic and sedimentary rocks.

17

PLUTO'S TREASURY

TREASURE hunts are fashionable features to-day in many efforts that are made to raise money for charitable purposes. Someone organizes the hunt, hides the treasure, and lays the trail. The victims of the effort do the hunting. In the hunt, now to be described, our mythical friend Pluto is the organizer and men are the hunters. Among the earliest treasures they found was gold, for archaeological excavations in Egypt and Mesopotamia have brought to light civilizations which, more than 3000 years ago, used gold for many purposes; for daggers, for lining coffins, for decorating the head-dresses of court ladies. Other substances rot and perish, but this gold is still as bright as when it left the hands of those ancient goldsmiths. Earlier still, however, copper was first used pure, and then mixed with tin to make bronze for a variety of tools and weapons.

How these rare metals were discovered is a mystery, for they were indeed very rare. We have already seen that 96½ per cent of the earth's crust is made up of the oxides of only seven metals. The remaining 3½ per cent is shared among more than three-score other substances, metallic and non-metallic, of which copper, tin, and gold make up a very small fraction. How did Pluto sort out this needle of rare metals from the great haystack of common rock-forming minerals? Part of that story has already been told. Much more has been culled from the observations of miners who have tracked down and exploited Pluto's hidden hoards.

One of the oldest, richest, and most illuminating of mining areas is Cornwall. Here tin and copper were obtained long before Julius Caesar landed on the shores of Britain. Here came Phoenician merchant sailors. In little ships, built for navigating the quiet summer seas of the Mediterranean, they braved the storms of the Atlantic to come and purchase tin from those

early Cornish miners. The fact alone testifies to the rarity of the metal. With all the known world before them, they found it worth while to run the risks of sailing through Atlantic gales to this outlandish spot.

From that day to this, with various ups and downs, mining has been carried on in Cornwall. The accumulated experience and knowledge gained by many generations make a most valuable and vivid contribution to the story of the ways in which Pluto gathered his treasures together and hid them in the secret recesses of the rocks, not only in Cornwall but in many other parts of the world. Let us then look at the story as it has been pieced together by geologists and miners.

The story starts with a granite magma emplaced in this area, some 200 million years ago during Permo-Carboniferous times, among the rocks which now occupy the Cornwall-Devon peninsula. This hot liquid contained in solution all the materials required for the manufacture of the minerals, both rare and common, now found in Cornish granites. A fact easily overlooked and forgotten is that these materials included as much as 9 per cent of water. As the liquid cooled, the molecules of the seven more abundant oxides came together and united with one another in various proportions and combinations. These crystallized out systematically as white and black mica, orthoclase felspars, large and small, and quartz, with a little tourmaline. In this way the main mass of the granite came into being, but its temperature was still high, in the region of 500°C.

When sea-water freezes, the salt and other substances it holds in solution are, so to speak, pushed aside and left behind. But the water in the ice itself is pure. Similarly, as the magma consolidated, a small fraction of the water it contained entered into the composition of the mica, but not into that of the felspars and the quartz. As the latter froze or crystallized out, the water and the rarer substances were pushed aside and thus accumulated in the small quantity of magma that remained. A large portion of this residual liquid was water, no longer wholly dissolved, but present in droplets, some of which became entangled in the quartz as it crystallized out and formed

the liquid inclusions described earlier. The water was still in a superheated state and under the great pressure of the overlying rocks. It was, therefore, a very efficient solvent, and helped to keep both rare and common minerals in solution along with sundry gases and energetic acids, such as fluorine, chlorine, and sulphuretted hydrogen. All this made up a chaotic mixture, a chemist's nightmare, but Pluto's dream.

Taken as a whole, the rock was now an almost solid mass except for small interspaces filled with this residual fluid. As the result of earth pressure faulting took place and fissures developed. These had a general trend from east to west, and traversed both granite and the surrounding rocks. Presumably these pressures, in conjunction with the shrinkage of the granite as it cooled, squeezed the liquid into the fissures and into the belts of shattered rock which lay alongside them.

As the temperature of the liquid declined, very large crystals of mica, felspar, and quartz grew and formed an exceedingly coarse-grained rock called pegmatite. In the States of New England and Dakota, in India and Brazil, the mica crystals in such dikes are sufficiently large to be exploited for a wide diversity of uses in commerce and industry. Occasionally the pegmatite dikes in Cornwall and Devon yield other minerals such as the gemstone topaz and the phosphorus-bearing apatite used for making valuable soil fertilizers.

This does not, however, exhaust the resources of this complex residual liquid. Continuing its way outwards along the fissures its temperature went on declining and a succession of minerals crystallized out. First among these was cassiterite or tin oxide, the chief ore of tin. Then came wolfram, a tungstate ore, and later various ores of copper, mainly as copper pyrites or copper sulphide. The tin diminished as the copper increased. These were followed by zinc blende, which in turn gave place to galena or lead sulphide, often impregnated with a percentage of silver. Finally sulphides of antimony, iron, and manganese were deposited in the outer extremities of the fissures.

These valuable ores do not occupy the whole of each fissure, but are more or less imbedded in other less useful substances spoken of, collectively, as gangue minerals. Chief among these

is quartz, which occurs throughout the fissure and may even extend as purely quartz veins far out into the surrounding rocks. In the deeper parts this is accompanied by tourmaline, but higher up by fluorspar, together with compounds of tungsten, sulphur, arsenic, and barium. Thus it comes about that the outer parts of the granite, together with a wide aureole of the rocks enclosing it, contain valuable hoards of minerals arranged in successive zones, a precious diadem crowning the head of the intrusive granite mass.

While all these complicated processes were taking place, a series of changes was produced in the walls of the fissures by the fumes which had ceased to help with the chemical transport of minerals. These permeated the rocks on either side of the fissure and there gave rise to new minerals. Boric acid attacked the mica and the felspar and produced tourmaline. Near the fissure the change was most complete and a dark-blue rock was formed which, under the microscope, is seen to consist of radiating needles of tourmaline in a matrix of quartz. Near the village of Luxulyan the large pink felspars of the granite remained unchanged and lay imbedded in a matrix of black tourmaline rock. This striking variety of rock is called luxulyanite; and was used in the construction of the Duke of Wellington's tomb in St Paul's Cathedral. Farther away from the fissure the tourmaline is present as long crystals. Those found in some parts of the world may be blue, red, or green and take their place among the gemstones.

The water vapours penetrated much farther into the granite and reacted chemically upon the felspar by removing the soluble potash and soda, but combined with the silica and alumina to form kaolin or china-clay. This mineral has for a long time been extensively mined for use in making china and porcelain.

All these plutonic activities took place in the Cornwall-Devon region in association with those great earth-movements which, at the close of the Palaeozoic era, gave rise to the Hercynian mountain system. This extended thence to the centre of France and on through the Black Forest region to Bohemia, where similar rich metalliferous deposits were formed.

These granite masses, with their precious diadems, were at first buried at profound depths far beyond the reach of man, even if he had been aware of their presence. Fortunately such surface agencies as rain and frost, rivers and glaciers have been working unceasingly for 200 million years and have levelled the mountains to a plain. With every movement of uplift that has taken place since, they have renewed their activities and stripped off the rocky covering, layer after layer, until at last the aureole of treasure hoards was reached. In places the covering was wholly removed and the granite itself was exposed to view. In this way the treasure stores were broken into, and part of their contents carried away with the waste formed from the rock which enclosed them. These were washed down into the streams and carried down towards the sea. Now copper ore is nearly twice as heavy, and tin ore three times as heavy, as quartz and the other minerals. While, therefore, the pebbles and grains of the lighter minerals went along merrily with the stream, those of these much heavier ores sunk to the bottom and lagged behind in the hollows and irregularities of the stream bed. There they accumulated and were buried under the gravel and alluvium which eventually carpeted the floor of the valley.

Here in the banks of the streams Bronze Age man, attracted by their difference in appearance and weight, gathered them and, by some happy accident, discovered that the heat of a fire extracted copper and tin from them. One step farther and he had made bronze. He and his successors found little difficulty in obtaining further supplies by digging trenches in the alluvium and uncovering the ore-bearing gravels beneath. Such sources of ore are known to miners as 'placer' deposits. From these placers the ancient miners supplied their own needs and those of traders who came from across the seas. As these reserves of 'stream tin' became exhausted the miner extended his trenches upstream and, in doing so, at last struck the outcrops of the original veins and fissures from whence the ore had come. He naturally began to excavate these also and found that, as he dug his trenches along the outcrop, he was led away from the valley floor up the valley sides to the moorlands above, and to further discoveries.

For millenniums the stream in the valley was doing the mechanical work of separating the light stones from the heavier, the useless pebbles from the valuable ore. During the same time, up on the moorlands, the rainwater percolated into the ground carrying oxygen and carbon dioxide from the air, and humic acids from the rotting vegetation in the soil, down into the rocks beneath. There it permeated the mineral vein, dissolved most of the minerals, and transported them in solution to the deeper parts of the vein. Some of the iron, however, remained and was converted into rust or hydroxide of iron. This gave to the waste that was left in the uppermost part of the vein a reddish colour, which distinguished it clearly from the rock on either side. The sharp-eyed quick-witted miner soon detected this 'gossan' as it is called, and used it as a guide for tracing the outcrop of the metal-bearing lodes across the moors, and for fixing the positions of new sites for opening up his mines.

As tin ore is very insoluble it remained as a residue where it was in the vein and thus a richer deposit was formed within easy reach from the surface. The other minerals were not merely dissolved and carried downwards, they were changed chemically into sulphates and carbonates, and were redeposited as such just above the water-table. Some of them, like the bright-green malachite and the deep-blue azurite, are quite attractive when cut and polished. They are often used as ornamental stones and for making cheap jewellery. When the descending water reached the ground water it mixed with this. The minerals were then reconverted into sulphide and redeposited as such. Thus it comes about that the vein, just above and below the water-table, was greatly enriched. As the miner was but human he naturally exploited these richer levels first. It was not until these were approaching exhaustion that he started off on the much more toilsome task of deep mining. It did indeed become truly deep, for some mines attained depths of more than 3500 feet. It is no wonder that new areas in other parts of the world, such as Malaya, have in recent times forged ahead of Cornwall in production.

For the sake of simplicity the story told above has been

mainly in terms of tin ore. It should, however, be borne in mind that the age-long process of stripping away the rocks, which covered the granite and enclosed its diadem, did not penetrate to the same depth in every vein. On the contrary in some it reached no farther down than the outermost zone where lead and zinc predominated. In others it uncovered the copper zone. Mines on the latter veins started as copper mines, but with increased depth they entered the tin zone and became tin mines.

The story of the Cornish mining area outlined above is typical of the other metal-mining areas of the world, the location of which will be found displayed in many atlases. Other examples of special interest may, however, be mentioned. As might be suspected there is a general relationship between the nature of an intruding rock and the type of valuable ore derived from it. Thus the suite of minerals found in Cornwall is usually associated elsewhere also with acid rock such as granite. It is so in Malaya, which is now the greatest metal-mining area in the world. There, however, much ore is still obtained from placer deposits.

That assemblage of minerals does not occupy such a prominent place in the New World. There silver and gold occur more frequently and are found mainly associated with igneous rocks of intermediate composition, especially near the great batholiths of the Pacific coast of North America in California and from Washington to Alaska. The formation of these began about 80 million years ago in the middle of Cretaceous times. Further intrusions, also accompanied by mineralizing fluids, took place in early and late Tertiary times. These brought up from Pluto's realms additional supplies of gold and silver with some copper and zinc. The last and most recent phase reached the surface in volcanoes and hot springs, which latter have yielded mercury.

The difference in age between the metal-bearing rocks of Cornwall and those of North America points to some kind of relationship between minerals and time, but as yet this is far from being understood.

In the case of the igneous masses just considered there was

manifested a tendency for the valuable mineralizing fluids to ascend through the magma and be released in the later stages of consolidation. In other cases, including the basic rocks, the tendency is for the valuable ores to crystallize out early and sink towards the floor of the magma. This was the case, for example, with the gabbro and allied rocks at Sudbury in Ontario. Here rich nickel ores, associated with copper and silver, gold and platinum, are found at the base of the laccolite, or in tongues intruded into the rocks beneath. Again, one of the largest masses of magnetic iron ore in the world occurs at Kiruna in north Sweden. It also is of magmatic origin, but opinions differ as to the precise steps by which it was brought into being.

As already seen, percolating water plays an important part in the local enrichment of mineral veins. A kindred process takes place under other circumstances. In the north of England the Carboniferous limestone was originally covered by a considerable thickness of Triassic rocks coloured red by iron. In that region there is a relatively gentle fall of rain at all seasons of the year which keeps up a supply of water continually sinking through the overlying rocks. This slowly leaches out the red iron oxide and carries it down to the rocks beneath. Here the water dissolves the limestone and deposits the iron in its place. In this way it has gradually gathered together those stores of fine-quality iron ore, haematite and limonite, which have for many years been mined in Cumberland and Westmorland.

In tropical lands the climatic conditions are quite different. There is a long dry season and a comparatively brief wet season during which rain falls in torrents. The water is warm and as it soaks into the rocks it dissolves out the soda and alkalis, the calcium and magnesium. This alkaline water in turn dissolves the silica, whether it be in the form of quartz or combined as silicate. The iron and aluminium, being much less soluble, tend therefore to accumulate in the residues left near the surface. These make up the rich red lateritic soils that characterize the tropical and monsoon regions. That, however, is not the end of the story, for the iron, being slightly more soluble, is

also gradually removed and consequently the aluminium comes to predominate in the residue. Thus extensive accumulations of bauxite are produced. This is widely used for the manufacture of aluminium, that strong light metal which to-day is used for a striking variety of purposes from the making of saucepans to the construction of aeroplanes. Gold, platinum, garnets, monazite, and other rare but relatively insoluble metals and minerals may also accumulate slowly in residues left by this type of destructive action by water upon the rocks in which they are so thinly scattered. Monazite yields cerium, a substance required in the manufacture of sparkers for cigarette lighters. These then are some of the ways in which the most skilfully hidden of Pluto's treasures have been made accessible to man.

Part Four: The Climates of the Past

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THE CLIMATIC PATTERN

VARIETY is the spice of life. Certainly the variety of climates on this earth makes a rich contribution of spice both to our travelling and to our reading.

For our knowledge of the climates of past ages we depend upon the records in the rocks. The pages of these are, unfortunately, badly torn and, for the earlier ages, very scanty. Moreover their evidence is drawn only from continental areas, and adjoining shallow seas, which could never have occupied more than about one-third of the surface of the globe. Deep oceans filled the remaining two-thirds, and appear to have left no record. By reason of their much greater extent, however, they must always have played a dominant part in the climates of the continents. They were, for example, the sole source of supply for the moisture which the air, as it circulated over the globe, deposited as rain upon the land.

When the moisture-laden winds pass from the oceans to the land they at first deposit their load generously over the coastal regions. Passing inland their reserves of moisture become steadily depleted and the rainfall diminishes. Towards the centres of the large land masses even showers of rain are rare, and arid conditions prevail except where the ground rises to great altitudes in lofty mountain ranges. All who have spent holidays among mountains know that the pressure of the air, as recorded by the barometer, declines steadily with increasing height. When, therefore, a wind blows up the slopes of these ranges the rising air is subjected to decreasing pressure and expands. Consequently its heat is distributed throughout a

larger bulk and its temperature lowers. This cooling process continues as the air rises until even the meagre store of moisture it still retains condenses and falls, as rain or snow, to feed the rivers and streams that flow down to, and even far out on to, the arid lowlands below.

The wind continues over the crest and descends the farther slopes. As it does so the air passes through all the same changes but in reverse. The pressure increases. The air is compressed, becomes warmer and drier. On reaching the lowlands, therefore, it tends to intensify the drought.

These phenomena are exemplified on the western side of the United States. There lofty mountains lie more or less parallel to the coast, athwart the course of the onshore winds, which they rapidly deplete of their moisture. On their windward sides the rainfall is so copious that forests with giant trees are supported. On their lee sides arid conditions prevail, as for example in the Great Basin region. The same is true also, but to a much less dramatic extent, for the corresponding latitudes of South America, including Patagonia, and for other parts of the world.

All these factors exert their influences within the much more important planetary control of climate. The principles underlying this control may be illustrated from our own daily observations and experiences. These arise, in the first place, out of the fact that, as the sun's rays pass through the atmosphere, they are partially absorbed. At noon the sun looks dazzlingly bright and its rays feel warm because they have passed through only a minimum thickness of air, and consequently suffered only a minimum of absorption. At sunset it looks dimly red and the evening feels chilly because the rays, before reaching us, have passed through a maximum thickness of air and experienced a maximum amount of absorption.

In the second place the angle at which the sun's rays strike the ground also has an important influence. Imagine a beam of sunshine to be a kind of cylinder. If the beam impinges on the ground vertically, all its brightness and warmth will be concentrated within a small area equal to a transverse section across the cylinder. If, on the contrary, it impinges at a low

angle, it will be spread over a much larger oval-shaped area equal to an oblique section of the cylinder. That is why, in the northern hemisphere, the soil of a garden situated on a south-facing slope is so much warmer than that of a garden facing north. Now consider the world as a whole. Because the earth is spherical the sun's rays, at noon, pass through a minimum thickness of air and strike the ground at a high angle in equatorial and tropical lands. In those regions the earth receives the maximum amount of heat from the sun and, therefore, temperatures are high. Passing outwards, through temperate to polar latitudes, the thickness of the air for the passage of the rays increases and the angle at which they strike the ground diminishes. There is consequently a progressive decrease in the amount of heat received and, therefore, a corresponding decrease of the temperature.

This zonal distribution of heat, together with the rotation of the earth, brings about a general planetary circulation of the atmosphere that controls the distribution of rainy and arid regions. In the equatorial zone the air becomes very warm at noon and in the early afternoon. It then rises in ascending currents. These produce great thunder clouds from which the rain falls in torrents amounting to as much as six inches in a day. Under these favourable conditions of heat and moisture vegetation grows luxuriantly and mighty forests are maintained. In swampy lowlands, which happen to be situated in this belt, fallen plant débris accumulates in considerable thicknesses of waterlogged peat. Should subsidence occur, this peat may be buried and in time be changed to coal.

Counterbalancing these ascending streams of air a system of descending streams exists over the tropical belts. Starting from altitudes where the air is cool and already dry, its temperature and relative dryness increase as it descends. On its arrival at ground-level it tends to absorb moisture and, therefore, to produce arid conditions. Here then, in the tropical belts, rainfall and vegetation are at a minimum and considerable expanses of desert and semi-desert result. The outstanding example of such a tropical desert is the Sahara, which merges eastwards through Arabia and Persia with the mid-continental deserts of

Central Asia and Mongolia. The corresponding features in the American continents are much less extensive.

The work of geological agencies in arid regions presents a remarkable contrast to that in the equatorial zone. The unclouded skies give unhindered passage for the incoming sunshine of the daytime and the outgoing radiation of heat by night. The great extremes of temperature that develop within the compass of a few hours shatter and pulverize the rocks. The wind picks up the fine waste and carries it to the lowlands. There the sand accumulates and drifts about as dunes. The dust may settle in dangerous pools between the dunes or be carried outside the limits of the desert to moister regions beyond. There it is deposited as 'loess'. In China loess, derived from Mongolia, has accumulated to depths of hundreds of feet.

The sand grains and dust particles are usually slightly coated with iron which, under these arid conditions, becomes completely oxidized and coloured red. This fact is dramatically illustrated by the 'blood rain' which sometimes falls in southern Europe. Its colour is due to dust borne by the wind from the Sahara.

The smaller rivers that descend from the mountains in arid lands build up fan-like deltas of gravel along the margin of the lowlands. On these human settlements are frequently established, for here water can be obtained from shallow wells sunk in the gravel, which acts as an underground reservoir. The overflow from this escapes from the margin of the delta and, fertilizing the surrounding soil, gives rise to an oasis. The ancient city of Damascus is a classical example of this kind of settlement.

The larger rivers that rise in these mountains flow farther afield, and form strips of alluvial plain across the arid wastes. In times of flood they spread over the plain depositing sheets of mud which subsequently dries and becomes suncracked. Here, then, within such inhospitable lands there are local conditions which support some vegetation and a limited amount of animal life. These are rarely preserved as fossils for they perish where they fall, but the tracks and footprints, made

upon the mud, may be preserved as the only records of a fauna that once lived alongside the rivers.

These rivers may end in lakes, but the water they contribute evaporates; the minerals it contained are left behind, and the lakes become progressively more salty, and may themselves ultimately dry up leaving behind them valuable deposits of minerals which to-day are extensively mined for use by industrial chemists.

Moving now into temperate latitudes we find that there the descending currents alternate with ascending currents. The former bring dry sunny weather; the latter, showers and steady downpours of rain, sufficient to support the growth of forests, but on a less magnificent scale than in the equatorial belt. Moreover, the temperature is lower and, during winter, is so low that growth ceases and the trees shed all their leaves. In ill-drained areas these, and other vegetable débris, accumulate and form peat deposits which in their turn may be ultimately converted to coal. It is important to remember that the presence of coal among the rocks does not necessarily reflect 'hot steamy climate'.

Beyond the temperate latitudes lie the polar regions. The geological conditions there are of such special interest that they will be dealt with in separate chapters.

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PRIMEVAL DESERTS

SHALES and sandstones, of Pre-Cambrian age, make up much of the lofty belt of mountains known as the North-West Highlands of Scotland. They are exposed along the sides of Loch Torridon and are, accordingly, named the Torridonian System. Thousands of feet thick, they fill up the valleys and bury the hills of a yet earlier landscape. This fact, together with their deep-red colour, shows that they were inland and not marine deposits. Among the shales sun-cracked surfaces of that far-distant age are preserved. Though signs of extreme aridity,

such as deposits of salt and gypsum, are lacking, these rocks do reflect a climate sufficiently warm and dry to bring about the complete oxidation of the iron on the sand and dust as they were being laid down. They also indicate that Scotland, which to-day is swept by Atlantic gales, was then situated deep in the heart of a large continent so far removed from the sea that the winds were depleted of their moisture long before they arrived. Similar rocks tell the same story about the climatic conditions which prevailed at the same time in the Great Lakes region of North America.

The Lower Palaeozoic rocks were mainly deposited in epicontinental seas. In North America, towards the middle of the Palaeozoic era, during late Silurian times, these seas withdrew from off the continent, except in the east. There a remnant, comparable in extent with the present Caspian Sea, was left covering the area now occupied by New York State, Pennsylvania, Ohio, Michigan, and South Ontario. As in the Caspian, there also the quality of the waters varied in its different parts. Towards the south-west, in the region of central Pennsylvania, a normal and abundant marine fauna flourished. This shows that the waters in that part of the sea were not appreciably different from those of the ocean. In the north and north-east direction, however, the waters became increasingly saline; so much so, indeed, that the sediments deposited in them now enclose salt beds having an aggregate thickness of 1600 feet. One of the sheets of salt, with an associated layer of gypsum occupies an area of 100,000 square miles. All this implies conditions of utter desert, of vast extent, over the surrounding country. Assuming that then, as now, the prevailing winds came from the west, it is interesting to note that the distance of this Silurian sea from the western seaboard of the continent was comparable with that which to-day separates the Caspian from the Atlantic.

In Britain and Europe normal marine conditions prevailed until the close of Silurian times when the Caledonian Mountain system came into being. That system followed a line which traversed Scandinavia from north to south; then curved southwestwards and crossed Scotland and Wales. It thus lay on the

windward side of a land mass that included the British and the north European areas. Destructive processes worked vigorously on these newly formed mountains and piled up deep deposits of boulders, gravel, and sand in the large intermontane valleys, which were occupied by extensive fresh-water lakes. On the low ground east of the mountains they spread thick sheets of red sand and marl, now known as Old Red Sandstone. The colour suggests that here in the lee of the mountain system semi-arid conditions prevailed. The water, in which these rocks were sometimes deposited, was fresh and supported shoals of an unexpectedly varied assortment of fishes. Some of these are of more than usual interest, for they were closely akin to *Ceratodus*, the 'mud fish' of Australia. Like other fishes this has gills by means of which it can breathe the oxygen dissolved in the water. During the long dry season the rivers, in which it lives, shrink and become strings of stagnant pools with water fouled by rotting vegetation and, therefore, quite unfit for breathing. As a second line of defence, against the seasonal return of such unfavourable conditions, lungs have also been evolved. When, therefore, the drought sets in the fish buries itself in mud and thus keeps its body moist. The tip of its snout, however, peeps out sufficiently to enable the creature to breathe air. This may, or may not, be a close picture of conditions in Old Red Sandstone times. Nevertheless it does illustrate a way in which fishes at that time became air-breathers. It is interesting to note that it was among these fishes that land animals had their origin. The earliest remains of land animals that have been found come from the late Old Red Sandstone rocks of Canada. The Old Red Sandstone period, therefore, is one of unique interest.

In Cornwall and Devon rocks of the same age occur; but they are mainly of marine origin, as shown by the presence of numerous fossils of corals and other sea animals. Some of the layers interbedded with them, however, strikingly resemble Old Red Sandstone and indeed yield some of the same fossils. There is, therefore, no doubt that these rocks are the marine equivalents of the Old Red. As it is the custom to take the marine rocks of any system as the normal, similar rocks of the

same age in Cornwall, Devon, and elsewhere, are appropriately called the Devonian.

In England, as also in other regions, the Old Red rocks are overlain by another series which yield large quantities of coal. Naturally the early geologists gave particular attention to these and, while doing so, realized that another set of red rocks overlaid them. These were accordingly named the New Red Sandstones, a name which, unlike the Old Red Sandstone, has now almost gone out of use. This is due to the fact that when they were investigated in other lands they were found to include rocks belonging to two separate systems. In the Russian province of Perm the lower portions were discovered to be typically marine in origin and contained fossils closely allied to those of the Palaeozoic rocks. They were, therefore, named the Permian.

On the other hand in Germany the upper part was shown to have a threefold division, a fact which suggested the name Trias for this system. The rocks consisted mainly of red sandstone and marl, but in the middle was a limestone. In the Alpine and Mediterranean regions the whole series consists of limestones and other marine rocks. A parallel change takes place in North America where, as in Europe, they yield numerous fossils that are closely akin to those found in the Mesozoic rocks.

The boundary between the Mesozoic and the Palaeozoic system of rocks, therefore, passes through the middle of the New Red Sandstone. In the field it is relatively easy to point this line out when marine fossils are present to serve as a guide. Usually, however, the typical New Red is unfossiliferous over extensive areas. It is then impossible to say where the Permian ends and the Trias begins; the two are then referred to collectively as the Permo-Trias.

These red rocks are more world-wide in their distribution than those of any other system. That stamps the Permo-Triassic period as one in which desert conditions were more widely spread than at any other time during the earth's history. This state of affairs seems to have arisen out of a combination of contributory causes. In addition to the ever-present tropical dry belt, earth movements resulted in the upheaval of new mountain systems on a grand scale. On the lee sides of these

considerable arid areas came into being. In addition there was a general elevation of the land masses accompanied by extensive withdrawals of epicontinental seas. These changes also favoured the further spread of desert and semi-desert conditions.

More or less completely land-locked remnants of those seas persisted in the central and south-western parts of the United States and across Europe from Britain to Russia. They were, however, large enough, like the Caspian to-day, to go trespassing through surroundings of varying degrees of aridity. The salinity of their waters, therefore, varied from place to place. In areas of increasing salinity, as for example in the north of England, the many forms of animal life, which survived from the original sea and peopled the Permian, declined. Corals, stone lilies, and other lovers of normal clear sea-water, gradually perished. The remainder, consisting mainly of lampshells, became dwarfed in size and then disappeared. Further desiccation of the climate led to increased evaporation and the deposition of masses of anhydrite and gypsum. In the neighbourhood of Stassfurt in Germany this process advanced to the extreme limits, for not only were the less soluble constituents of sea-water, such as salt and calcium sulphate in the form of anhydrite and gypsum, deposited, but the much more soluble ones, chlorides, sulphates, and other salts of magnesium and potash, were also laid down. For many years these deposits gave to this part of Germany pre-eminence as a supplier of agricultural fertilizers and materials for various chemical industries. Salt deposits on a much vaster scale were laid down in the Ural region of Soviet Russia and from Kansas to New Mexico in the United States.

Similar climatic conditions continued on into Triassic times. In Britain Triassic rocks occupy practically the whole of the Midlands with long extensions south to Devon and north to the Midland Valley of Scotland. The Trias of the English Midlands supplies in miniature a replica of the Triassic records which occur on a much grander scale in the United States and other parts of the world. Its basal portions consist of coarser sandstones. These are followed by bedded fine sandstones and red marls which reflect a brief period during which rainfall was

sufficiently heavy for the establishment of sheets of fresh water, peopled with shoals of fish. The rapid recurrence of beds of sandstone and marl or clay points to a seasonal rainfall which filled up the lakes and brought quantities of sediment of which the sandy portion settled down first, and was subsequently covered with mud. In the dry season the waters shrunk and fishes, trapped in isolated pools, buried themselves in great numbers in the mud and sand and awaited the return of fresh floods of water. Sometimes these did not return, and the shoals of fish were preserved as fossils to tell the tale. As the water shrunk, parts of the muddy floor were left exposed. Very often, before this had time to dry hard, animals ran across the damp surface leaving their trails behind them and hundreds of footprints. The mud, with these prints, was baked hard. When the floods came once more, the sand filled the prints and covered the mud. To-day when these beds are exposed the mud layer may perish quickly, but the sand which filled the prints, having been turned to rock, supplies us with models of the animals' feet. From these models, and similar casts of the trails, much may be learned about those animals, their size, the length of their stride, whether they had short legs and waddled like a duck, or had long legs and ran swiftly like a dog. Unfortunately, that too often is all that we know about them, for their flesh perished and their bones were destroyed. Nevertheless some actual fossil remains have been found. One, called *Rhynchosaurus*, differs only in minor details from the New Zealand lizard. Another tiny reptile, with the big name *Schleromochlus*, was no larger than a frog. It had long hind-legs and leaped across the landscape like a kangaroo or, better still, like the tiny jerboa of the asiatic steppes and semi-deserts.

In among the fossil sand-dunes of the Trias, south of Birmingham, traces of an oasis in that ancient desert landscape were found. These included remains of plants and scorpions. These facts furnish additional evidence in favour of the climatic inferences summarized above.

This mildly pleasant interlude in the middle of the Triassic period was followed by a prolonged time of extreme aridity. When the brief rainy season came it covered parts of the flat,

monotonous landscape with sheets of very shallow water, comparable with the playa lakes in the Great Basin region of North America. Dust brought by the winds, mud, and silt brought by the seasonal streams, were spread out in thin laminae on the floor of the water. Breezes playing across the surface of the water produced ripples on the mud beneath. In the dry season the water evaporated leaving the mud with its rippled surface encrusted with salt. When the streams returned with fresh supplies of water and of salt the playa filled once more; the salt encrustation was dissolved. This process was repeated until the water was so saline that when it evaporated the salt was left behind as beautiful cubical crystals partly buried in the mud. Once more the floods returned, the crystals were dissolved, and the cubical space left behind was filled with silt. In time this turned to stone. To-day the geologist splitting the rocks often finds surfaces covered with these cubical pieces of stone, popularly described as 'fossil salt cubes', technically as 'salt pseudomorphs' (false forms), having the shape of salt crystals, the substance of silt. Similarly the presence of 'fossil' rain-prints and sun-cracks add their testimony to the picture just given of the climatic conditions that prevailed here in pastoral England long ages ago. Not all the sheets of water in that monotonous landscape were so ephemeral as playas. Some of them lasted continuously for long stretches of time. Eventually they became so saline that valuable deposits of salt, anhydrite, and gypsum were precipitated and accumulated in their depths.

A similar progression from moist to arid conditions took place also in other parts of the world, but on a far grander scale. In the Karoo of South Africa fossil plants and even reptiles are frequently found, but more will be said about them in a later chapter. There also desiccation of climate set in and arid conditions were established. A comparable story is told by the Triassic rocks from the Ural region of Russia and the Parana basin in Brazil. In western North America Triassic rocks range from Idaho to New Mexico over an area six times that of Great Britain. There, as elsewhere in the world, these rocks to-day give rise to colourful landscapes such as 'The

Painted Desert' in Arizona. In that area during Upper Triassic times conditions in some localities were favourable to the growth of giant conifers, the fossil remains of which are to be seen in the 'petrified forest'. There fossil logs, as much as 100 feet long, and 10 feet thick, have been measured.

The Triassic period was brought to a close by the setting in of slow movements of subsidence, accompanied by gradual submergence, and an extensive return of epicontinental seas. These spread outwards from Tethys, the great Mediterranean sea, which crossed the Old World from east to west. Much of eastern North America, however, remained dry land and was subjected to prolonged denudation and peneplanation.

In Great Britain there is no sign that the Triassic surface underwent appreciable erosion. On the contrary the sea steadily spread over it. No doubt inundations took place at times of unusually high tides. Occasionally the sea then broke into saline lakes bringing with it multitudes of fishes and marine reptiles. These all perished as the sea-water became mixed with the highly saline lake waters. That is a slightly gruesome interpretation that may be put upon the presence of 'bone beds' near the base of the first marine deposits laid down upon the Triassic surface.

From this time onwards until the oncoming of the epoch in which we are living there was no return of widespread arid conditions. Where such did occur, as for example during Jurassic times, in and around the Colorado region, they were limited in extent and were the outcome of local circumstances such as the presence of uplands on the windward side.

In the present epoch, however, arid conditions have once more become widespread; probably favoured by the growth of great new mountain systems during Tertiary times, and an associated general rise in the level of the continents.

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PRIMEVAL WOODLANDS

THE evidence for the existence of moist climates, whether hot or temperate, is not so obvious in the colour and other characteristics of the rocks themselves as we have seen to be the case for arid climates. It is more convenient, therefore, to rely upon the fossils they contain, more especially those of plants; for plants are often delicate indicators of climatic conditions.

Plants did not become established upon the land until the close of the Silurian and during the Devonian periods. For early Palaeozoic and Pre-Cambrian times plant evidence for the study of climate is, therefore, not forthcoming. Animal remains are practically unknown in Pre-Cambrian rocks, but they are often abundant in the early Palaeozoic rocks. Their evidence, however, is not very illuminating for they were all marine animals. Obviously they can furnish no clue as to whether the climate of the region where they lived was moist or dry. On the other hand some of them, such as the corals and the stone lilies, do reflect the temperature, for their allies to-day live in warm, clean, sunlit tropical seas. Among the Silurian rocks occasional limestones are found in Europe and North America in which corals and stone lilies abound, thus indicating that the climate in these more northerly latitudes was warmer then than now. Nevertheless it is upon the plant remains that we must chiefly rely for this brief study of the moist climates of the past.

In Carboniferous rocks, plant remains are extraordinarily abundant. So much so, indeed, that at many different levels their accumulated remains have produced coal seams. As already seen, these were first deposited as waterlogged masses of vegetable débris. Underlying many of the seams are the ancient soils upon which the plants grew. These contain thick root-bearing underground branches of trees whose trunks were surrounded at the base by peat. This part of the tree has

become incorporated in the coal. Parts of these trunks are, however, preserved in the overlying rocks. In these it is not unusual to find fossilized tree trunks 2, 3, and even 4 feet thick, with an estimated height of 100 feet. They are, therefore, worthy to be called forest trees.

These Carboniferous coal-bearing rocks occur along a zone in the northern hemisphere which extends from China, through south Russia, Germany, Belgium, the British Isles, and the United States. That this was a belt of copious rainfall in Carboniferous times is evident, but it is not so evident whether the temperature was hot, warm, cool, or cold. The luxuriance of the vegetation and stature of the trees exclude cold. The limestones with which the seams are frequently associated are often rich in corals and stone lilies. This fact suggests abundant sunshine and tropical temperature.

The timber from our temperate forests usually has a clearly marked grain or rings of growth. The presence of these reflects the great seasonal change from winter to summer. In equatorial timber, however, such grain is not strongly marked and is often absent. This is associated with the uniformity of temperature and moisture all the year round and consequent uniform growth. Here, then, is a feature which it was hoped might help in the solution of this problem. The evidence already collected points to uniformity of growth conditions but as yet is not completely convincing. On the whole, opinion favours the view that conditions which exist in the sub-equatorial dismal swamps of Florida represent moderately closely the conditions under which the Carboniferous coal-measure forests flourished.

A passing reference may be made here to an interesting view that has been put forward. It is that in Carboniferous times the equator lay along the zone already described as extending from China to the United States, in what are now the temperate latitudes. Since then it has shifted into its present position. The temptation to enter into a discussion of the many implications involved in this idea of a shifting equator must be resisted. We are finding instability of the earth's crust enough to cope with. Wandering poles and shifting equators make matters a little too complex.

The coal measures of the southern hemispheres open out a very different set of problems, for they are closely associated with fossilized glacial deposits. The plants which contributed to the production of coal seams on that side of the world must, therefore, have grown under cold temperate conditions.

After the long Permo-Triassic period of very dry climates epicontinental seas returned and, except for a slight recession at the close of Jurassic times, went on extending until they reached a maximum in late Cretaceous times. Their surface currents had a correspondingly greater freedom of circulation and thus played an important part in extending moist and less extreme climates into higher latitudes.

The Jurassic rocks themselves throw a sidelight upon the problem of climates. In England, for example, they consist of three alternating accumulations of clays and limestones. This fact suggests that there were oscillations between moist and drier phases of climate. During the former the rainfall was relatively copious. The land was low-lying and consequently the efflux of water was slow and sufficed only to wash the finer sediments, silt and mud, down into the sea. This teemed with multitudinous forms of animal life, including large aquatic reptiles. The limestones, on the other hand, reflect drier, but not extreme, conditions which produced a minimum of waste from the land. The waters of the sea were clear and sunlit, ideal for the growth of small coral reefs and some stone lilies. On the beaches, round grains of lime abounded. These resemble the roe of a fish and are known as 'oolite' grains. Some were formed as the result of being wetted by the wavelets of sea-water rich in lime, and then dried by the sunshine. Each time this happened an exceedingly thin film of lime was left upon the surface of the grain. Others were covered with minute algae which extracted lime from the water, and thus the grain increased in size. Many Jurassic limestones consist largely, or even entirely, of oolite grains, and are excellent building stones such as that which has helped to make the city of Bath so famous.

Among the Jurassic rocks of Yorkshire there are considerable deposits which were laid down in estuaries where sand and silt

brought down by rivers built up sandbanks and mud-flats. On these, vegetation grew in sufficient abundance to form peat beds which have since been turned into thin seams of coal. These rocks yield numerous fossil remains of cycads or tree-ferns, an attractive group of plants which flourish to-day in forests of the warm temperate belt in the southern hemisphere. Their remains preserved in the rocks of Britain indicate that the same pleasantly warm moist climate prevailed here also during the Jurassic period. Similar conditions, suitable for the formation of coal, were at that time widely spread over the world. They developed, however, on a large enough scale to give origin to valuable sources for the supply of coal in regions as far apart as Tasmania, Australia, Spitzbergen, and Greenland. Evidently throughout that period warm genial conditions extended into much higher latitudes than they do to-day. Indeed it seems doubtful whether even the polar ice-caps existed then.

During the slight recession of the seas from off Britain at the end of the Jurassic period an interesting series of deposits, 400 feet thick, was formed in the south of England. These are known as the Purbeck Beds. They consist of a mixed assemblage of marine and fresh-water limestones, with marls and 'dirt' beds. These last are ancient soils which have yielded numerous fossilized stumps of tree-ferns which grew on that spot. The Upper Purbeck beds in one area contain valuable deposits of gypsum which were formed under special local conditions. A small body of sea-water was isolated from the open sea by a low barrier, and was subjected to rapid evaporation. From time to time it was replenished by the sea swilling over the barrier. Eventually its water became so concentrated that gypsum was precipitated. This could only have happened under warm sunny conditions.

With the opening of the Cretaceous period transgression of the land by the sea was renewed. In southern England, during the early Cretaceous, a large fresh-water lake existed which was centred on the Wealden area. Into this lake rivers built out deltaic flats on which reptiles roamed and vegetation grew which resembled that of Jurassic times, and reflected a

continuance of the same type of climate. In Greenland, beds of approximately the same age and formed under estuarine conditions now yield fossil remains, especially of fallen leaves, derived from a varied assemblage of quite a different type, no longer reminiscent of the past, like those of the Wealden, but anticipatory of the future. It included such modern bushes and trees as the magnolia and cinnamon which to-day inhabit tropical and sub-tropical lands; and also oak and plane, denizens of the mild temperate forests situated where the alternation of seasons induces an autumnal shedding of the leaves. These fossils, which to-day in Greenland lie cheek by jowl with glaciers and ice-fields, point to the existence in their day of a much more genial climate in those high northerly latitudes; a climate that fulfilled the needs of such exotic plants as magnolia and cinnamon as well as those of the more tolerant oak and plane.

In the western states of America a broad seaway stretched from the Gulf of Mexico to the Arctic Ocean. Along its western margins similar conditions existed to those already depicted for the Wealden Lake, but on a far larger scale and for a much longer time. Rivers, bringing sediments down from the newly risen and rising uplands, built out extensive deltas and alluvial, often swampy, flats. They supported forests with the same type of mixed flora as that just described for Greenland; including willow, hazel, poplar, as well as magnolia. The fallen débris from these built up bulky accumulations of peat which ultimately produced those great coalfields that are distributed from Montana to New Mexico. Unfortunately, the coal is not of outstanding quality. All this adds up to impressive testimony to the uniformity of warm moist climatic conditions that spread across many latitudes from the opening of the Cretaceous to the dawn of Tertiary times.

A strikingly different picture is outlined by the Lower Cretaceous rocks of Central Australia. There some of the layers contain large erratic blocks which could only have been transported to, and dropped in, their present position by icebergs drifting into the seas where the original sediments were being laid down. Other layers yield fossilized logs of conifer

trunks which must have grown under much less severe conditions than those reflected by the presence of icebergs, but nevertheless much more severe than those just described for similar latitudes in the northern hemisphere.

The warm climates that prevailed even in high latitudes throughout the Mesozoic era continued into Tertiary times. Flowering plants, which are the crown of vegetative evolution, had now become well established. The study of their fossil remains along with those of plants belonging to lower grades throws an interesting light on the later phases of the story of climates. That story may be illustrated by reference to a few examples.

The clay which underlies London and much of the Thames Valley was laid down during the early Tertiary, in Eocene times. In the Isle of Sheppey this clay encloses plant beds from which the fruits of the genus *Nipa* have been obtained. This palm lives to-day alongside estuaries that open into the Indian Ocean, and its fruits are often seen floating down the rivers which flow into them. Fossil evidence shows that *Nipa* also grew freely in South Russia. Apparently it disappeared from these more northerly latitudes before the close of the Eocene. The palmetto, which flourishes to-day in the West Indies, Florida, and Mexico, also grew in England, France, and south Germany until the opening of the Pliocene or last phase of Tertiary times. Magnolia which was so prominent even in Greenland during the Cretaceous continued to hold its own for a long time as far north as the Arctic. But during the Pliocene its northern limits had shifted as far south as France. A similar restriction in distribution of the bread-fruit and fig tree likewise took place. This retirement southwards of the exotic elements of the Tertiary flora points to a slow, but progressive cooling of the climate in middle and higher latitudes. This became more rapid and intense towards the close of the period.

During the Pliocene the primitive Rhine, and its distributaries, pushed out a great delta westwards from the German borderlands. In these deposits plant remains were buried at different times during the growth of the delta. An analysis of

the genera and species thus preserved shows that there was a progressive decrease in the number of exotic and extinct types from as much as 94 per cent to as low as 31 per cent. At the same time the flora as a whole became increasingly like that of this part of Europe to-day. From this it is evident that the progressive cooling of climate, indicated earlier, had advanced more rapidly in Pliocene times.

A similar, but even more striking, story is told by a parallel series of changes which took place in the faunas of the North Sea. These are recorded in a succession of East Anglian shore deposits rich in fossil shells. The earliest fauna thus preserved included forms characteristic of southern and northern seas amounting to 26 per cent and 1 per cent respectively. In successively younger layers these percentages undergo a steady change. That for the southern forms decreased until it disappeared completely. That for the northern rose until in the latest deposits it was as much as 33 per cent, and included some shells which occur to-day in the Arctic seas.

Thus the long reign of warm and genial climates, which in these northerly latitudes had lasted on through the Mesozoic and most of the Tertiary eras across nearly 200 millions of years, was brought rapidly to a close by the onset of cool, then cold, conditions which culminated in the great Pleistocene or Quaternary Ice Age which will be dealt with in succeeding chapters.

21

SNOW AND ICE

A SNOW-FLAKE looked at through a magnifying glass is an object of great beauty, made up of star-like crystals whose rays resemble miniature fern leaves turned to glass. Each crystal corresponds to one of those tiny particles of moisture which drift round us in a cloud or a damp mist. Under wintry conditions these freeze and become snow crystals which float in the air like 'dandelion down' and, becoming entangled with

one another, form snow-flakes. These descend from the clouds and cover the landscape with a white garment.

Though each crystal is made up of transparent ice, snow is of proverbial whiteness, because the sunshine is reflected back from the myriads of facets which make up the surface of each radiating icy fern. Presently the warmth of the sunshine melts the individual crystals beginning at the tips of the rays, and turns the flake into a drop of water, which during the night may freeze into a grain of ice.

On the lowlands in temperate latitudes a fall of snow may either melt away in a day or two, or, augmented by other falls, remain until spring returns with longer days and stronger sunshine. Then all the accumulated snow of several months melts rapidly, and for a week or fortnight the landscape is sodden, the streams become torrents, and the rivers swell into floods. Even then some snow may linger under the shadow of the hedgerows or where deep drifts were formed.

In the uplands, where it is cooler, the snow stays longer and, in sheltered hollows, may remain until summer. At still higher altitudes, as in the Swiss Alps, it lasts on until the following winter. The snows of successive winters are piled one upon another, where the ground is relatively level, but on steep slopes it slips and avalanches down into the valleys. The depth and extent of these snow-fields in the Alps tends to diminish eastwards for the rain-bearing winds come from the west and yield less and less moisture as they pass inland. Because the western Alps of Switzerland are easily accessible it is they, rather than the polar regions, that have long been the geologist's laboratory for the study of snow and ice, and of the work they do. With the increased speed of travel in recent years there has been a growing tendency for students to go to arctic lands for their glacial studies.

The unit surface feature for snow-fields in mountain regions the world over is an amphitheatre-shaped hollow on the mountainsides, known as a corrie or cirque. Here snow may accumulate to a depth of two or three thousand feet. As each fall of snow becomes buried deeper and deeper under later falls, it is subjected to increasing pressure. This causes the snow

crystals to melt at their points of contact until each becomes a grain of ice, and the air between is squeezed out. Thus the white snow gradually changes into compact transparent, but still essentially granular, ice. Under pressure from above and from upstream the grains slip past one another. The ice mass as a whole behaves as though it were plastic and glides forth from the cirque along the valley into which it opens. The glacier thus formed is often described as a 'river of ice'. Like a river it flows more quickly along the centre than along the sides, and at the surface than near the floor. A river, however, flows at a rate of three or four miles an hour, but a glacier may flow only that number of feet a day; though some Greenland glaciers flow as much as 60 feet a day.

The surface of the upper reaches of a glacier, like that within the cirque, is always covered with snow; for it lies above the snow-line, where the summer sunshine fails to melt the winter snows. The lower reaches of the glacier, however, having crept below the snow-line, are not so covered. There, not only the winter snow but also some of the ice is melted. Because of the great bulk of ice and the relative smallness of its surface, it may creep a considerable distance down the valley before it melts away completely. As its bulk diminishes its rate of flow slows down until, at last, it comes to a standstill at the foot of the glacier.

Below the snow-line the sunshine warms the rocks along the sides of the valley. This warmth is radiated towards the glacier and melts its sides, thus giving to these a steep slope. Along the gully formed between this slope and that of the rocks the melt waters flow away.

The surface of the snow higher up within the cirque naturally slopes towards the valley exit, for the ice is moving in that direction. There is, in consequence, a tendency for the ice and its snow covering to pull away from the sides of the cirque. Around its margin, therefore, a deep crack or crevasse, known as the *bergschrund*, develops. This constitutes a serious obstacle to climbers approaching the mountainside from the snow-field. The surface of the glacier itself is also broken by crevasses, due to the differences between the rates of flow of the ice in the

centre and at the sides. Above the snow-line the blocks between the crevasses are flat topped; but below the snow-line they are melted into 'seracs' with sharp crests and steep sides, thus making the surface almost impassable for any who wish to cross the glacier. The melt waters cascade down into the crevasses to the floor and, flowing down stream, make a tunnel through the bottom ice, finally emerging at the foot.

With the severe daily and seasonal changes of temperature, frost works vigorously on the valley sides, breaking off chips and loosening blocks of stone. These tumble down on to the surface of the glacier and form long heaps, or lateral moraines, upon its margins. Sand and small pieces of stone, warmed by the sunshine, melt their way down into the ice. On the other hand a large block serves the purpose of a sunshade. While the ice round it is being melted, that in the shade remains and eventually becomes a pinnacle with the boulder on the top. Some of the pinnacles encountered by the Everest party on the Khumbu glacier are described as being nearly 100 feet high. When a crevasse opens, parts of the moraine fall down and become incorporated in the ice below. In these and various other ways the rock waste is transported by the glacier and finally deposited at its foot. There, with the melting away of the upper layers of ice, the lower are exposed to view and are seen to be crowded with sand, gravel, and boulders. In the end these also are dumped down in a crescent-shaped heap, the terminal moraine, that stretches across the valley from side to side. Unlike the deposits laid down by a river, these constituents are not sorted out, but are inextricably jumbled together. Again, in a river the stones, as they are rolled along, become beautifully rounded; but in a moraine they retain much of their original angular form. The water escaping from the ice foot in numerous streamlets deposits gravel in an apron-like sheet across the valley floor.

Small glaciers at all stages in the development of such a unit as that just described are to be seen from horse-shoe-shaped drifts of snow around the edge of the cirque to the fully developed combination of snow-filled cirque and valley glacier. The melt waters from the glacier escape as a considerable

stream which, after being joined by other streams from similar glaciers, discharges into a large river. This, with its multitude of tributaries drains an extensive area of the mountain region. The arrangement of the valleys in that area, or drainage basin, is the same as that of the streams and consists of a main trunk valley with numerous branches or tributary valleys. The unit fields and glaciers form the outermost twigs of the system, and lie near the rim of the basin, which is bounded by mountain peaks and jagged edges.

Among loftier mountains with heavier snowfall the cirques are filled to a greater depth, and the glaciers extend so far down stream that they unite and form a larger glacier in a larger valley. The lateral moraines from the smaller glaciers pass on to the main one and are carried along as parallel heaps in midstream.

In the Himalayas, which rise to still greater altitudes, examples occur in which the glaciers are more fully developed. Snow is brought by the monsoon winds, which blow from off the Indian Ocean. Here again the total fall diminishes as the winds penetrate farther into Asia. This is reflected in the fact that the snow-line on the southern side of the range is 3000 feet lower than in Thibet. It is under these conditions that, in some drainage systems, even the trunk valley itself is occupied by a large glacier, fed by glaciers joining it from every tributary valley.

Examples still more fully developed are furnished by the mountain systems in Alaska, where for much of the year the snow-line descends far down on to the lowlands. The drainage systems there are filled to the brim with ice and snow which, as they emerge on to the foothills, spread out fanwise and thus form an 'expanded foot glacier'. The Malaspina glacier which results from the union of several expanded foot glaciers has an area of 1500 square miles.

The mountain belt of Scandinavia differs from those referred to above in that the highest portions of the latter form a plateau. Here the combination of high latitude and relatively high altitude, within the reach of moisture-laden winds, has led to the accumulation on the plateau surface of large caps of

ice and snow. Similar, but more extensive, ice-caps occur near to, or just within, the Arctic circle on Iceland and Spitzbergen. They provide a transition to the consideration of polar and continental icefields.

In the northern hemisphere the largest of these is in Greenland. It occupies an area of half a million square miles, and rises to an altitude of more than 9000 feet. In recent years attempts to find out the thickness of the ice by methods akin to echo sounding give a thickness of 8000 feet resting upon a floor 1600 feet above sea-level. This sheet thins gradually towards the coast, near which mountain peaks sometimes rise through the ice, standing up like islands, known as 'nunataks', in a sea of snow. At its margin lobes of ice spread out on to the plateau like promontories, between which glaciers creep down the valleys to the sea. There the ends of the glaciers often break off in the water and float away into the ocean as icebergs, with only one-tenth of their bulk above water. This part melts into fantastic shapes, while the slightly warmer surface waters of the sea make a wave-melted, rather than wave-cut, platform around the margin. This lies submerged, and is a serious source of danger to ships that approach too closely. It is not always easy to avoid doing so, for the iceberg, as it drifts southwards, cools the air around and is often enshrouded in fog.

The great northern icefields all lie some distance from the Pole which is situated in the middle of the Arctic Ocean. On this the snow does not accumulate, but the water is frozen to a depth of only a few yards. This area for a long time had a greater fascination for explorers than had Greenland, for it offered two unique attractions. One was the North Pole, the other the possibility of finding a passage to the Pacific round North America. Brief reference may be made to only one of the many voyages of discovery, namely that made by Nansen in search of the North Pole in 1893–5.

The successful outcome of this voyage was as much due to careful scientific thinking as to physical endurance. The Arctic Ocean is almost completely surrounded by land. It has, however, two main exits; a narrow one leading to the Pacific

between Alaska and Siberia, and a broader one between Greenland and Scandinavia which opens into the Atlantic. Into this ocean large volumes of water are poured by great rivers from Siberia and Canada. The only escape for the excess of water is through these passageways. On the basis of these, and many other observed facts, Nansen built up a general idea of the circulation of the arctic waters. Assuming that the ice would be carried along in accordance with this, he estimated that if he entered the ice-sheet at a certain point, he would eventually drift across the site of the pole. He, therefore, set out in a little ship, the *Fram*, that had its hull so shaped and protected that when the ice closed round, it would not be crushed but be lifted on to the surface. The line of drifting passed sufficiently near to the pole for him to reach it by sledge. His views on the oceanic circulation were confirmed, and so another solid contribution to our knowledge of the earth was made. Getting to the pole, of course, is not the only purpose of these expeditions. They are always equipped for collecting information on climate; on the movements, quality, depth, and temperature of the ocean waters; on fish and bird life, earth magnetism, and so forth.

In the southern hemisphere, on the other hand, the polar region is occupied by a small continent, the Antarctic. This is almost completely covered by the largest ice-sheet on the globe. Unlike the Greenland icefield, this usually extends beyond the land out on to the sea, and forms a vast floating platform upon which snow accumulates. Great blocks break away from the free edge of this platform and float away as tabular or flat-topped icebergs. One ice-cliff left by the carving off of these bergs is 300 feet high and 500 miles long, and is an insuperable barrier to explorers seeking to enter the continent along that stretch of its margin. This is known as the Great Ross Barrier. Near other stretches of the coastline mountains and even volcanoes rise up through the ice, and glaciers flow between them and down to the sea.

This vast area of icy cold surface exerts a remarkable influence upon the atmospheric circulation, which is the reverse of that exerted by the high temperatures near the equator. The

air lying in contact with the ice becomes very cold and heavy. It, therefore, flows down the spacious slopes of this continental icefield from the centre towards the sea. As it does so, large volumes of air are drawn down from the sky above to the centre. On coming into contact with the ice this air, likewise, becomes so intensely cold that the very small amount of water it contains is frozen to a fine snow which, as it settles, replenishes the icefield.

This descending and outward flow of air continues normally for about three or four weeks, and may go on longer. At first the movement is quite gentle. Gradually the speed increases from being a stiff breeze until it becomes a furious gale. It was an unusually long spell of this kind that defeated Captain Scott. As the descending air comes under great pressure it is compressed. Just as the repeated compression of the air in a bicycle pump makes it hot, so the temperature of this current increases. At last it may be so warm that it tends to rise and to act as a brake, that gradually slows down the rate of flow until all is calm and still once more. After a while this mighty heat machine begins working once more. This process is repeated rhythmically and unceasingly as long as this icefield, or indeed any icefield of continental proportions, exists.

22

SNOW AND ICE AT WORK

ENERGY has been defined as that which does work. As already seen, water in rapid motion, whether as a river in flood, or in waves lashed by the wind, does a vast amount of work. But water that is frozen solid, what can it do? Among the mountain heights it seems to do no more than share in the beauty and majestic stillness of the peaks around. Nevertheless, as we have seen, it does move very slowly, but enough to enable it to play a striking part in the shaping both of mountains and of valleys. How it does that work is more a matter of intelligent inference than of direct observation. The lateral moraines, carried along

on its surface and dumped at its foot, testify to its transporting powers. The boulders, stones, and gravel, seen in the lowest layers at the foot and in the sides of the tunnels which run under the glacier, the muddiness of the waters that flow along these, all bear the same testimony.

Many of the blocks of stone, dumped by the ice, have their angles rubbed off and their surfaces scored with scratches. These facts suggest that the floor of ice, armed with these stones, moved along like a giant file, and ground away the rocks beneath as it flowed over them.

In 1760, the Swiss geologist De Saussure noticed that downstream from the foot of the glacier the surfaces of projecting rocks along the valley floor looked strikingly different from those up on the valley sides. The latter, shattered by frost, were rough and jagged; but the former were rounded, smooth, and covered with fine scratches, aligned in a direction which pointed down the valley. On every hand stones and boulders, like those dumped by the melting ice, lay scattered about. From all this he concluded that the glaciers themselves had once extended much further down the valley, grinding the rocks as they advanced and depositing the stones as they retired. His observations and conclusions were not believed until they were confirmed in 1840 by the great Swiss naturalist Agassiz, who subsequently became a professor at Harvard University. These startling discoveries were then soon accepted generally. Observations that have now been made over a period of years show that in fact the glaciers are again receding slowly, leaving behind them further evidence of their methods of working.

One interesting feature about the ice-rounded hummocks of rocks, described by De Saussure as 'roches moutonnée', was that the rounded surface faced upstream, because it was on that side that the full impact of the filing action was felt. On the downstream side the surface dropped in a succession of rough steps as though the ice, as it flowed away from the hummock, had pulled away blocks made loose by the presence of joints. This method of working is called 'plucking'. Evidence of plucking action has been observed by venturesome explorers

deep down in the great crevasse which lies near the margin of the icefield in a cirque. As the ice moves away from this gathering ground it grinds at the rocky floor, and its margins pluck at the bases of the precipices around. At the same time the frost shatters the faces of these. In these ways each cirque is steadily deepened and enlarged until at last its walls first abut against and then intersect those of the adjoining cirques. The crest, along the line of intersection, is a narrow ridge, to which the descriptive name of 'razor edge' has been given. As this encroachment of one cirque upon another continues, the skyline of the razor edge descends in a curve, the lowest part of which serves as a col between the two cirques.

If three pennies are laid in a triangle upon a table and pushed together, so that they touch one another, a triangular space will be seen left between them. In like manner when three adjoining cirques encroach upon one another a triangular-shaped peak is left between them. The Matterhorn and Everest are examples of this. Similar conditions recur at intervals along the crest-line of a mountain range, thus producing a skyline pierced by a succession of peaks separated by down-curving cols. This type of topography is described as alpine and, as we have just seen, is the outcome of the combined action of frost working at precipitous slopes and of ice sapping at the base.

A main valley glacier is much larger and bulkier than the tributaries that feed it. The vertical pressure it exerts upon its floor is consequently greater, and its deepening action correspondingly more powerful. The outcome of this is that the floor of the main valley is ground down sometimes far below the level of the floors of the tributary valleys. These, with their glaciers, are left high up on the sides of the main valley, like pictures on a wall, and are described as hanging valleys or hanging glaciers. The water from the latter descends in falls down to the main stream. In a main water-worn valley the hills which separate the tributaries project into the major valley as spurs and the river, skirting round the tips of these, pursues a sinuous course. But a large glacier relentlessly strives for a straight course and, to secure this, cuts away the tips of the

spurs. The presence of such truncated spurs even in regions where no glaciers exist is an infallible sign that at some time in the past glaciers travelled that way.

Another new and very beautiful feature is introduced into the landscape when the glacier finally disappears. During its existence, by grinding its floor, it deepens this below the normal level. At its foot, however, the ice is standing still and does no grinding; the valley at this point is not deepened, but remains at its natural level, which is higher than that of the deepened floor farther upstream. At this point, therefore, there is a natural dam across the valley. This dam is raised in height by the crescentic moraine which has been built upon it. The upshot of this combination of conditions is that the overdeepened part of the valley becomes filled with water. Thus a lake comes into being. Practically all the lakes in mountain regions have been produced in this way.

The investigations, started by De Saussure, have since been carried on by an increasing number of workers, whose observations show that in the distant past the alpine glaciers extended beyond the mountains on to the Swiss plateau and the Italian Piedmont slopes. There the ice spread out fanwise into expanded foot glaciers, whose former limits are now defined by more or less semicircular moraines. These enclose hummocky country, covered with boulder clay, at the centre of which there is usually a large lake, as for example Lakes Lugano, Geneva, and Constance which extend upstream into the valleys.

Now that their eyes were opened to see the evidences of the former presence of glaciers, naturalists and geologists began to find them in areas far removed from the Alps. One of them, enthused by his discoveries in north Wales, said that there the 'valleys shouted glaciation'. Accounts of evidence of the same kind came pouring in from Scotland, Germany, Scandinavia, Finland, Canada, and the United States, in such volume that geologists and others were forced to believe the almost unbelievable: that vast areas of North-west Europe and of North America, now occupied by teeming millions of civilized people, were once not merely decorated with glaciers here and there,

but were literally buried under ice-sheets of continental proportions rivalling that now existing on the Antarctic to-day.

Over such continental areas all the features left by an alpine glacier along its valley floor were now seen reproduced on a vastly greater scale. Morainic heaps, rising to altitudes of 300 feet or more, wander across the landscape for thousands of miles, marking the line along which the margins of the ice-sheet rested for millenniums. In the plains of northern Russia and east Poland they formed a hummocky belt of country spattered with innumerable lakes, lakelets, and marshes. Though it rises to an altitude of only a few hundred feet it forms the chief water divide of Eastern Europe. Here the great rivers, Volga, Don, Dniester, and Dnieper rise and, flowing southwards, at last pour their waters into the Caspian and the Black Sea. Down its northern slopes smaller rivers flow and find their way into the Baltic.

From Poland this morainic belt travels westwards across Germany and the British Isles. In America it stretches westwards from Newfoundland, following a relatively straight course across the northern states to the Pacific coast. Midway it bends southwards in a wide bulge roughly defined by the rivers Ohio and Missouri. As it crosses the western mountains it is joined by the northern end of a long strip of icefields occupying the higher crests.

In Germany the margin of the ice rested on ground that was rising in altitude towards the Alps. The melt waters released every summer, unable to escape in that direction, gathered together in a series of temporary lakes which overflowed westwards to the North Sea. The finer products of glacial scour were deposited in these lakes, which to-day no longer exist, but their sites are occupied by a succession of patches of very fertile soil. These present a contrast to a parallel series of barren heath lands, made up of gravels laid down by the outwashed waters alongside the moraine. In the United States on the other hand, as in Russia, the melt waters gained easy access to the sea by way of the Mississippi and its tributaries.

These continental icefields exerted the same influence upon the atmospheric circulation as the Antarctic does to-day. The

recurrent strong winds that blew outwards from the icefields swept across the adjoining tundras, sucked up the finest dust, and carried it into the more temperate regions beyond. Here, as the wind lost its force, the dust was dropped and accumulated. The deposit thus formed is known in Europe as *loess*; in America, as *adobe*. Wherever it still lies uncovered it produces soil of exceptional fertility.

As the climate ameliorated, the ice-sheets melted and shrunk. This shrinkage was not uniform. Now and then there were temporary returns of more severe climate, when the margin of the ice halted and built up additional morainic ridges. Normally, however, the retirement went on steadily through successive summer seasons, leaving spreads of boulder clay over the countryside that partially smothered features produced earlier by the grinding action of the ice. Here and there between the moraines, or against rising slopes, the melt waters were held up in temporary lakes in which the finer sediments were laid down that to-day form patches of fertile soil.

In Europe the direction of retirement was towards the Scandinavian highlands, except for that portion which lay over the British Isles. This latter separated off along the adjoining margin of the North Sea. In Britain the ice-sheet completely disappeared, but on the mainland of Europe relics still survive in the Scandinavian ice-caps. In Canada the shrinkage of the main mass north-eastwards took place across the Hudson Bay which was then uncovered. The western portion which originated in the Cordilleran mountains retired to its place of origin. The existing icefields in Greenland, Ellesmere Land, and the islands of the Arctic are all probably memorials of that strange period of time popularly known as the 'Great Ice Age'.

Much of the area of country that was covered was subjected to the scouring and grinding action of the ice. The features produced were largely controlled by the variable quality of the rocks of the Basement complex, which makes up the Baltic and Canadian shields. Where these were more resistant, smooth rounded rises of ground remained. Where it was less resistant, hollows were scooped out which are now occupied by countless

lakes of all shapes and sizes. Finland, the Outer Hebrides, Manitoba, all show this type of glaciated landscape ideally developed. The original drainage system was, of course, destroyed, and to-day the water flows from lake to lake 'in wandering mazes lost', though ultimately it escapes somehow into the sea. The archipelago, off the Finnish coastline, is an example of the effect produced by the submergence of this type of hummocky landscape.

As seen in an earlier chapter the Basement complex passes, at the boundary of the shield, under a covering of sedimentary rocks. Along the line that marks the fringe of these the ice found softer material to work on and scoop out. The more extensive hollows it made are marked to-day by a series of larger lakes such as Ladoga and Onega in northern Russia, and Great Bear and Great Slave lakes in the Canadian Central Provinces. These are sometimes referred to as 'glint' line lakes. The Baltic Sea, Hudson Bay, and the Great Lakes have a different type of origin in that they occupy areas which were depressed under the load of super-incumbent ice and have not yet fully recovered.

23

EARLY ICE AGES

In his novel, *The Time Machine*, Wells gives a vivid picture of a rapidly cooling world in which the inhabitants are slowly dying out as the sun's power declines and a state of eternal frost and gloom sets in. To a generation that could produce and read with approval such a book, the Great Ice Age, revealed by a close study of the landscape, seemed to be but a foretaste of things to come. The reverse of that picture was indicated by the formation, in very early geological times, of the Basement complex with its evidence pointing apparently to a landscape of heated rock and ablaze with multitudinous volcanoes. To-day these nightmarish visions have been dispelled or at least pushed so far forwards or backwards in time as to

disturb no longer the dreams of the most apprehensive and fearful of men or women.

In earlier pages it has been seen that at least 1000 million years ago the sea teemed with living creatures with the same flesh as plants and animals have now – 'for all flesh is one flesh'. There is no reason for thinking that living substance in those far-off days differed appreciably in its physical needs from that of to-day. The known abundance and variety of living things in Cambrian seas, and presumably also in Pre-Cambrian, shows that optimum conditions of temperature and composition existed for living organisms then as now. As the seas exert so important an influence on climate it is safe to assume, therefore, that the general climatic conditions have undergone no great permanent change.

To all this may be added the fact, now fully established, that the Ice Age referred to in the last chapter was by no means unique. On the contrary it was but the last of a series of such ages recurring at very long intervals far back into Pre-Cambrian times. In the North-west Highlands of Scotland that great accumulation of Pre-Cambrian sedimentary rocks, known as the Torridonian, rests upon what appears to be a typically glaciated surface of Basement-Complex rocks closely resembling the present scenery in Finland and Labrador.

In North America, in the Lake Superior region, the middle Pre-Cambrian rocks yield a fossil boulder clay, known as *tillite*, in some places 600 feet thick and ranging from east to west for a distance of 1000 miles. This must have been the product of a continental ice-sheet existing there 1000 million years ago. In north Utah rocks of late Pre-Cambrian age, or possibly early Cambrian, contain tillite associated with consolidated outwash gravel, interbedded between normal formations of sand and shale. Together, they mount up to a total thickness of 12,000 feet, and suggest the picture of a series of Ice Ages following one another in close succession.

Similar tillites occur among the Pre-Cambrian rocks of Norway, Greenland, China, India, south-west Africa, and Australia. The last-named region, however, yields the most impressive evidence of Pre-Cambrian glaciations, for there

nearly every type of glacial product is seen. Perhaps the most interesting are the glaciated boulders which are found imbedded in normal sedimentary rocks. These were evidently dropped down in seas infested with icebergs which, as they melted, released the rock waste picked up by the ice-sheet that produced them.

It is impossible to tell, at present, the extent to which these widely scattered evidences of Pre-Cambrian Ice Ages may be precisely correlated in time with one another, but it is certain that at least two such very early periods of glaciation occurred.

Late Palaeozoic times witnessed another of these major frigid oscillations of climate. Traces, possibly due merely to valley glaciers, have been recorded from the British Permian rocks. The most impressive evidence, however, comes from rocks of about the same age in the southern hemisphere. In those days an ice-sheet covered much of South Africa and, in the Karroo region, produced tillites 2000 feet thick. In south-east Australia tillites are developed on the same scale, but there they are present as five sheets separated by rocks containing seams of workable coal. These indicate warm interglacial spells. Similar evidences of glaciation occur also in peninsular India, the Argentine, and south-eastern Brazil.

This scattering of ice-sheets around the Indian and South Atlantic oceans presents a puzzling problem. One plausible explanation is proffered by the supporters of the theory of Continental Drift. According to this all these areas, together with the Antarctic, were in late Palaeozoic times parts of one major continent, called Gondwanaland. In that case all these ice-sheets would belong to one majestic sheet. If that were so, then the fact that some of the boulders, in the South American tillites, apparently came from South Africa would cease to be inexplicable.

Throughout the Mesozoic and Tertiary eras the climates in the northern hemisphere, and possibly also in the southern, were much warmer than now. Indeed it seems quite probable that the polar ice-caps of the present age were then non-existent. Towards the end of the Tertiary a gradual deterioration of climate set in which culminated in yet another, and the last, of

the Ice Ages. As this one was of such recent occurrence the traces it left behind are more fully preserved than are those of any of its predecessors. The details of the events which took place during its history are much more fully known.

An outstanding point of interest about this last Ice Age is that it began about the same time that man, as real man, appeared on the earth, and spans across nearly the whole of his period of existence. Because man is so supremely interesting to himself he has exalted this period to the status of an era, which he calls the Quaternary. So far it has lasted only one million years, and therefore is not comparable in length with any of the other eras. What the era lacks in time is presumably more than made up for by man's own superb qualities.

The Quaternary is sub-divided into two parts; the Pleistocene, which was coextensive with the Ice Age, and the Holocene, which includes all subsequent time, both prehistoric and historic. Because of its importance as a background to the study of Prehistory, the Pleistocene or Quaternary Ice Age will be considered in detail in a subsequent chapter. Before passing on to this it may be of interest to glance briefly at the question, 'What caused these Ice Ages?' There is as yet no consensus of opinion upon this, but several suggestions have been made of varying feasibility. From the astronomical side, it has been suggested that, from time to time, our solar system passed through regions of space, where conditions existed that interfered with the normal supply of heat from the sun. From the geological side, it has been pointed out that there is a certain relationship between the distribution of glacial periods through the ages, and the distribution of periods of mountain building. In association with such movements, not only are the mountains themselves elevated to considerable altitudes, but also a general uplift of the continents as a whole takes place. At such times of maximum elevation of the land, much more of its surface was situated in the cooler levels of the atmosphere. The lower temperature resulting from this would favour the establishment of glacial conditions over extensive portions of the land. Again, if the continents did indeed drift about, such drifting might, sooner or later, take the land masses into the

polar regions and the development of continental icefields would naturally follow. The same result would be forthcoming if it were the poles and not the continents that shifted round. None of these explanations accounts for the periodic return of warm interludes during the Ice Age. There is still hope that the students of climatology and meteorology may come forward with explanations that will throw satisfactory light upon this problem. For the present we must rest content. The more detailed study of the last Ice Age may lead a step or two farther forward.

24

THE LAST ICE AGE

SWISS geologists, living in surroundings where glaciers and the results of glacial activity abound, continued to be the pioneers in this new and fascinating branch of Geology. Towards the end of the nineteenth century terraces capped with river gravels, situated near Innsbruck, attracted their attention. In one of these two boulder clays were found, a lower and an upper separated by a fossil-bearing breccia and by river gravel. The fossils included the remains of plants that no longer live in Switzerland, but in the warmer regions farther south. This discovery opened out an entirely new line of thought in the study of glacial geology. The presence of the remains of these plants could only mean that for a time, within this Ice Age, the climate of Switzerland was much warmer than it is now. So warm, indeed, that the glaciers themselves must not only have shrunk, but have disappeared entirely. The upper boulder clay showed that, after a while, this warm interlude passed away, and was succeeded by another spell of ultra-severe climate, during which the glaciers returned and an intense cold prevailed.

This discovery was followed by others, which left no doubt that the Ice Age was made up of a succession of glacial stages or *glaciations*, during which the ice returned and advanced to a maximum and then retired and even vanished. These stages

were separated by warm *interglacials* whose total duration did, in fact, exceed that of the glaciations. This term 'Ice Age' is, therefore, to some extent a misnomer. Nevertheless it serves a very useful purpose, as a popular term that covers the whole sequence of glaciations and interglacials. In the Alpine region four glaciations were recognized, consisting of two pairs. The earlier pair was separated from the later by a very long warm major interglacial, which lasted about four times as long as any one glaciation. Minor and cooler interglacials separate the members of the two pairs. Much smaller sub-divisions have been recognized, but they need not be detailed here. Maximum severity and extent of icefields occurred during the second of the earlier glaciations.

From all that has been said in previous chapters it is evident that the geological work done by various agencies associated with rivers on the one hand and with glaciers on the other leaves strikingly different impressions upon the landscape. In consequence of this each glacial and each interglacial has left behind its own distinctive records; sometimes full, sometimes fragmentary, upon the scenery around us, both among the mountains and on the lowlands. Since man has always been more at home and carried on most of his activities in the latter, the limited space at our disposal must be devoted to the lowlands.

Early man, hardy as he must have been, did not live his life upon the ice-sheets. On the contrary his natural home must always have been far from these, in regions of warmth and comfort. To suggest as some have done that Ice Ages have played an important part in the evolution of mankind must not be taken seriously. The close association in our minds of prehistoric man with Ice Ages is quite accidental. Then as now, there were always men gifted with the spirit of adventure who enjoyed going forth from the homeland to explore the unknown. Some of these made their way across Europe and came into the west, possibly during an interglacial period. Even during a glaciation they held their own bravely in the tundras that fringed the ice-sheet. It just so happened that, during the last few centuries, Western Europe has been one of the chief centres of civilization. Here, as late as the nineteenth century,

the remains of prehistoric man and relics of his activity were first discovered. It was not in their ancient homeland but here, where those early explorers made for themselves new homes, that the foundations of the study of prehistory were first laid. Thus it came about that prehistoric man and the Great Ice Age became closely linked together in human thought. We must now discuss the scenic aspect of those foundations. The human aspect will be considered later.

Picture the conditions that existed in that countryside where man lived, when it lay in close proximity to the ice-sheet, during one of those periods of glaciation which lasted about 20,000 years. It was not covered by ice, but the climate was of arctic severity. In the winter successive falls of snow lay on the ground and accumulated. In summer it all melted and the rivers and streams swelled up into flood. At the same time the margins of the icefield also melted and spread sheets of gravel over the adjoining area. This water added its quota to the floods and, in addition, brought large quantities of stones and gravel as well as of sand and mud. The latter were carried freely down to the sea. The former were rolled along and, with their aid, the flood waters deepened their beds and widened their channels to a breadth of 2, 3, and even 4 miles.

Turn now to the conditions which prevailed during the warm interglacial period which followed. In winter rain fell and usually there was no snow. After every fall of rain the water ran away forthwith into the streams and rivers, which were then about the same size as they are now and flowed all the year round. The main river, like a narrow silvery ribbon, meandered from side to side along the broad flat-bottomed vale, which had been excavated by the much greater summer floods of the glaciation period. Normally the river kept to its narrow channel and spent its energy in spreading gravel on the floor over which it meandered and in carrying mud and sand to the sea. Century after century more gravel was laid down, until it attained thicknesses of 10, 15, or 30 feet. Meanwhile prehistoric man camped out on the river flats and spent his time hunting, fishing, and making his implements. Many of the latter were cast aside or were lost and became buried in the

successive levels of gravel, the earliest in the lower layers and the latest in the upper.

During each succeeding period of glaciation the process of down-cutting was repeated, and thus a new channel was excavated within the previous one. Usually it was not quite so broad. Strips of the old channel, capped by gravel, were left running like terraces for varying distances along the valley sides. These are called river terraces. During each subsequent mild or warm interglacial period the process of aggradation, or building up the gravel deposits, was repeated. One result is that to-day several terraces at different levels may be present, arranged one above the other in a series of cyclopean steps. The floor of the existing valley carries the youngest gravel. The surface of the highest terrace has, preserved in it, relics of the oldest or earliest gravel-covered floor. The intermediate terraces commemorate intervening periods of time. Here then upon the landscape are features which, like the figures on a clock face, mark off intervals of time and form a basis for fixing the relative ages of implements, and other relics of prehistoric man that are found in the gravels.

Followed upstream, the valley with these features traverses across the foothills up among the mountains where sheets of outwash gravels and morainic heaps of boulder clay occur. Here it is possible to establish the relationships of the various gravels that are preserved on the terraces to the outwash gravels and their associated boulder clays left by the successive glaciers that once occupied the valley. The account, given at the opening of this chapter, of the terrace at Innsbruck illustrates the way in which this can be done.

It was upon such evidence as the above that the workers in Alpine areas sub-divided the Pleistocene into four glacial and three interglacial episodes. By holding up the four fingers of your hand you can make a diagrammatic representation of their scheme. The fingers represent the four glaciations. The second, or longest, finger corresponds to the glaciation which had the maximum extent and intensity. Now spread the fingers, making the space between the second and third four times greater than that between the others. This space stands for the

main interglacial which was not only the longest, but also the warmest. This divided the glaciations into two groups, an earlier and a later, each with its own short interglacial.

By studying the rates of growth of deltas, in some of the large lakes since the glaciers left their margins, these workers estimated that the time which had elapsed since the final phase of the last glaciation was from 16,000 to 24,000 years. One of them, Penck by name, carried his enquiries farther back. He investigated the depths to which the glaciers deepened the valleys during each glaciation, and also the extent to which soil weathering had penetrated into the older and the younger boulder clays. On the basis of this work, he calculated that the length of the first and of the last interglacial was 60,000 years, and that of the long or main interglacial, was 240,000 years. Making allowances for the glacial periods, he formed the opinion that the total length of the Pleistocene Ice Age was 600,000 years.

This work has been followed up by a multitude of other workers in a correspondingly careful study of the tracks and trails of continental ice-sheets in Europe and North America. The story elicited from these is in general accord with that told by the alpine evidence. It is natural that, with so much more abundant and more widely spread material, many better opportunities were forthcoming for the discovery of further detail. Thus, for example, the morainic hills produced by the younger boulder clays are practically unmodified by denudation, and the hollows between are still occupied by lakes and lakelets. But in the older boulder-clay belt the hill features have become subdued as the result of prolonged denudation by rain and frost. The lakes have been drained. The rivers and streams have assumed the more systematic arrangement of a normal drainage system.

Again, anyone who has done a little gardening is familiar with the distinction between soil, subsoil, and rock. The two former have been derived from the last by the penetrating action of water, frost, oxygen from the air, and the roots of plants. These between them have not only pulverized the rock, but have changed the colour and content of the product by

chemical action. Careful observation of undisturbed soils that have been newly formed within historic times has enabled workers to make estimates of the rate at which these changes travel down into the ground. On the older boulder clays they have penetrated much more deeply than on the younger. This fact confirms the evidence from the modification of surface form and of drainage that a considerable length of time elapsed between the formation of the older and the younger boulder clays.

As each period of glaciation declined the ice-sheets receded towards their centres of origin, leaving behind them boulder clays, gravels, sands, and silts distributed over the landscape. When a new glaciation developed it overwhelmed and destroyed considerable portions of these relics of the earlier glaciation. Fortunately this fate did not befall the records left by the last one and consequently it has been possible to study them more fully. As an upshot from this work it has been discovered that the retreat of the last great ice-sheet was not continuous but oscillatory. That is to say, in addition to making prolonged halts it sometimes readvanced. Two major re-advances have been recognized, separated by recessions indicating minor slightly warmer phases. The former are called stages, and the latter interstadials, to distinguish them from the main glaciations and interglacials.

Frequent references have been made to longer and shorter periods of time. These naturally stimulate the question, 'How long?' For instance how long is it since the last glaciation? Thanks to work started by the Scandinavian geologist De Geer, and carried on by many co-workers, some approach to a precise answer can now be given. It has been seen earlier that, as an ice-sheet retires, some of its melt waters do not flow away immediately but may be impounded or dammed back by minor moraines. During much of the year no melting took place and this temporary lake was frozen over. In the month of June melting began and increased to a maximum in late July or early August. Towards the end of September all became locked in frost once more. The waters of the lake were thus replenished every summer and they became turbid with sand, silt, and fine

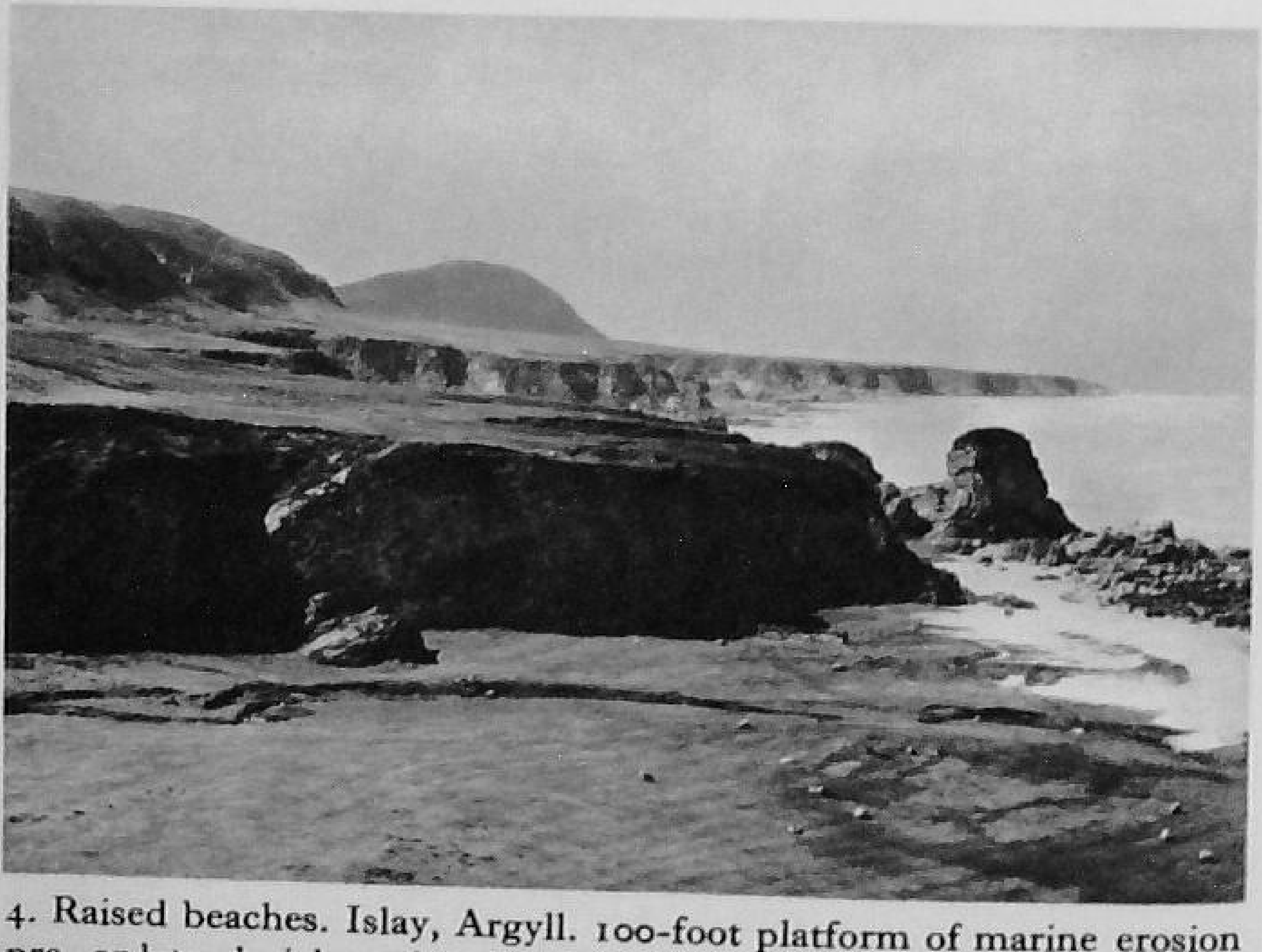
mud. These sediments settled in that order; sand first, then silt, and eventually, during the quiet of winter, the fine mud. The whole formed as a thin layer on the floor of the lake. This process was repeated annually. To-day these deposits may be found in clay pits, road-cuttings, and other exposures, where they are seen to be made up of many thin but easily distinguishable layers, called *varves*. Assuming that each varve corresponded to one year, De Geer conceived the idea of counting up the varves, formed in a series of lakes that had occupied a succession of situations, from the neighbourhood of Stockholm up towards the Scandinavian plateau. There the remnants of the ice-sheet still survived. In the midst of the series was one varve of unusual thickness and character. This he had reason to believe was due to a sudden access of water released when the two existing ice-caps first became separated from one another. The number of the varves above this showed that the separation took place about 6839 B.C. In round numbers that is about 9000 years ago from the present time. At last one purely geological means that was free from grievous uncertainties had been found for estimating time.

The breaking of the ice-cap into two parts at Ragunda was an event with only a local significance. Geologists generally felt that some other more influential event that would leave much more widely distributed impressions on the landscape should be chosen as the datum for pinpointing the end of glacial and the opening of post-glacial times. The event selected was the reduction of the ice-sheet to such small dimensions that it ceased to control the atmospheric circulation above and around it. The central Swedish moraine now marks the position of the ice margin at that time. Until then the south of the Baltic area was occupied by a large fresh-water lake. This was shut off from the North Sea by a barrier of higher ground. The ice margin impinged against its most northerly point, but there came a time, almost a geological moment, when the ice melted away from the tip of the barrier. The fresh water rushed through the gap thus made down into the sea. The surface of the lake fell nearly 40 feet to sea-level. From then onwards sea-water gained access to the Baltic and made recognizable

1. Fiord and hanging valley. Aurlands, Sorgne, Norway.

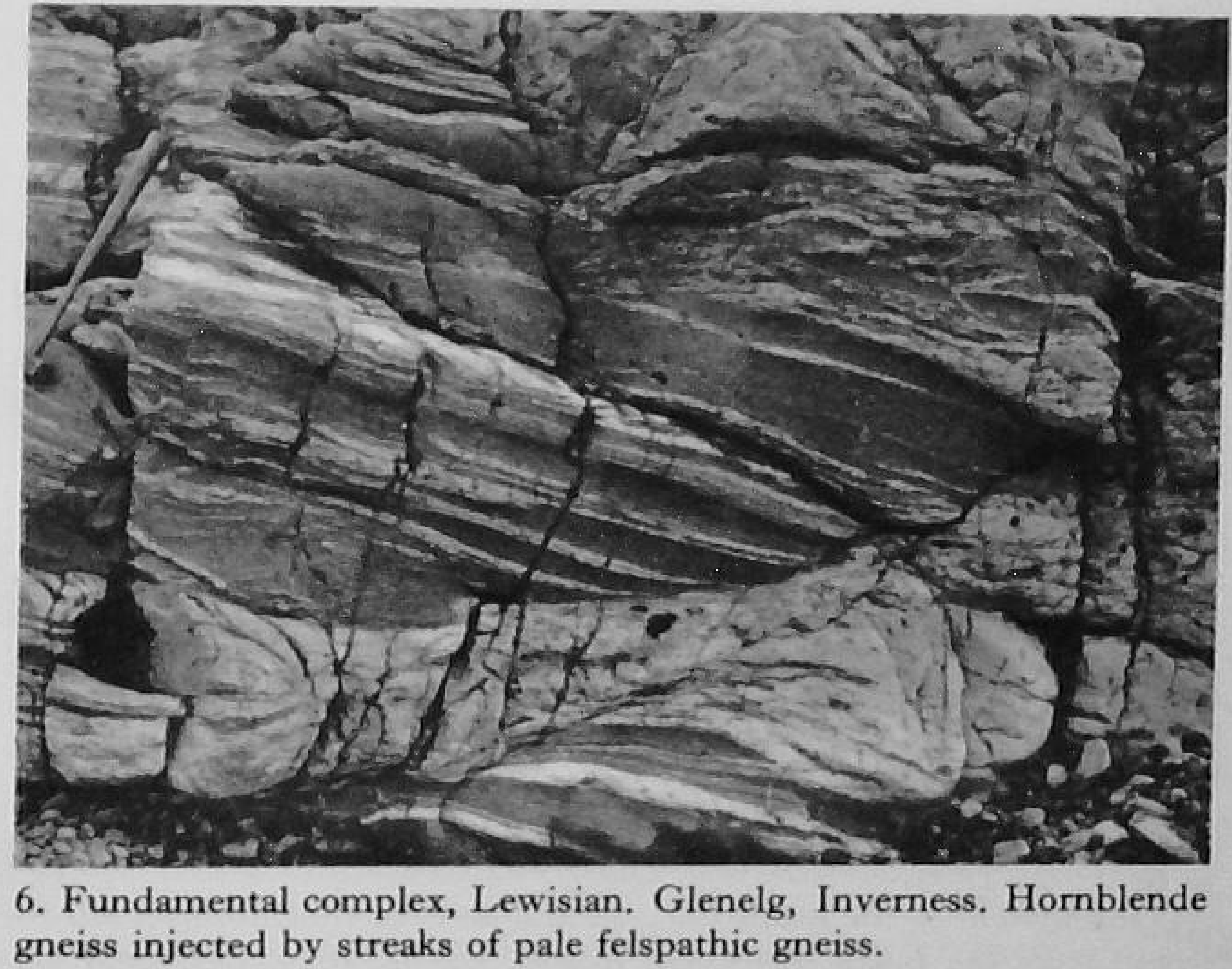
2. Spiral-nebula, Canes Venaticae.

3. Beach at Bridport, Dorset.



4. Raised beaches. Islay, Argyll. 100-foot platform of marine erosion pre- or late glacial. 25-foot beach in the foreground. Present beach on the right.

5. Contorted metamorphic rock. Loch Eck, Argyll.



6. Fundamental complex, Lewisian. Glenelg, Inverness. Hornblende gneiss injected by streaks of pale felspathic gneiss.

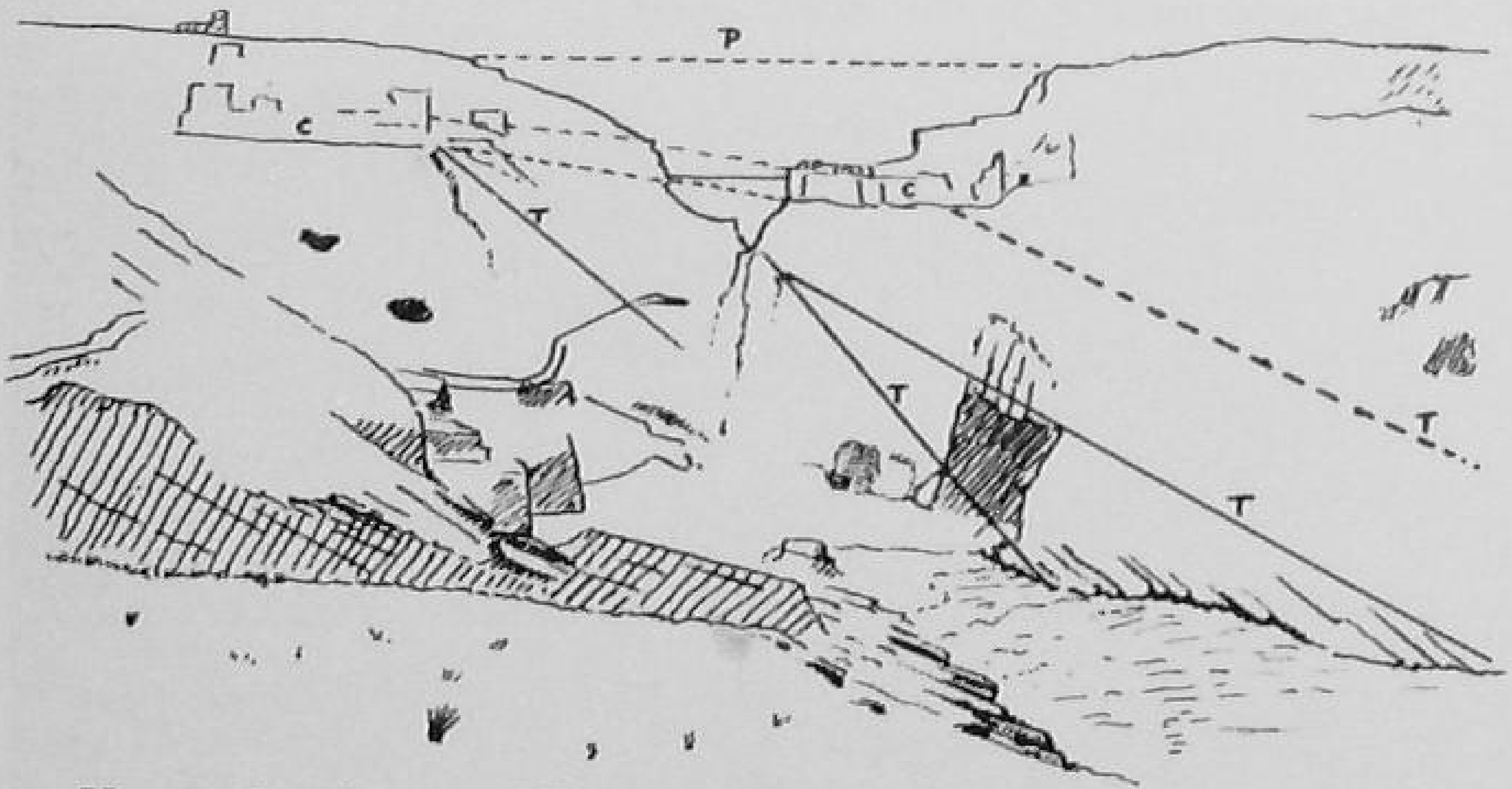
7. Present-day platform of marine erosion. Southerndown, Glamorgan. Skyline shows Tertiary peneplain.

8. Inundation by the sea in 1953. Sutton on Sea, Lincolnshire. All the sand from the beach was swept inland, leaving the clay foundations exposed. This brought to light medieval saltpans used for evaporating sea-water.

9. The upland plateau, Derbyshire. This platform, at about 1000 feet level, shows the subdued topography of a typical peneplained surface. This has been incised by the River Dove.

10. Sea cliff and boulder beach. Little Haven, Pembrokeshire. This shows bedded rocks folded and broken by a fault.

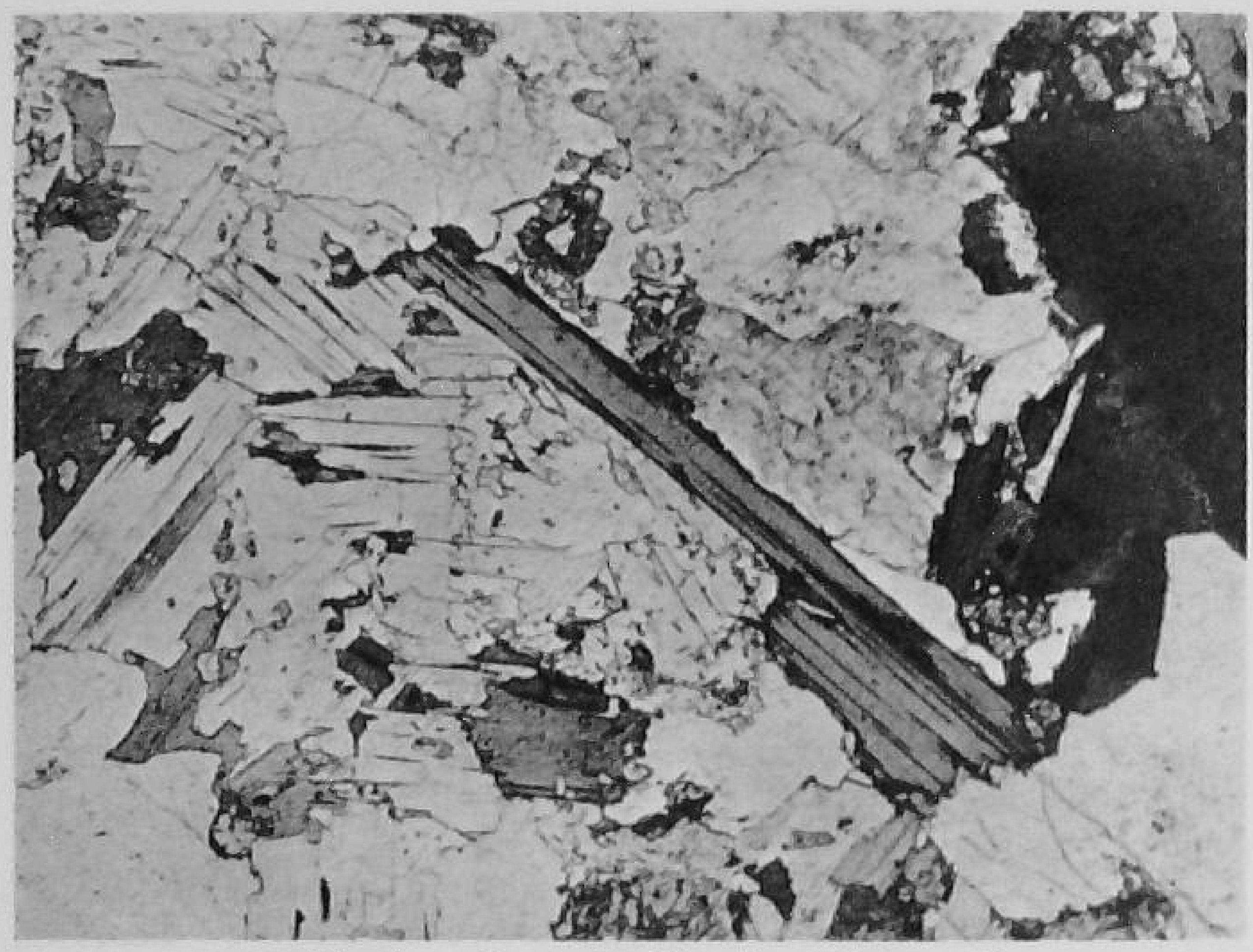
11. Tintagel Castle and Haven, North Cornwall. For explanation see figure below.



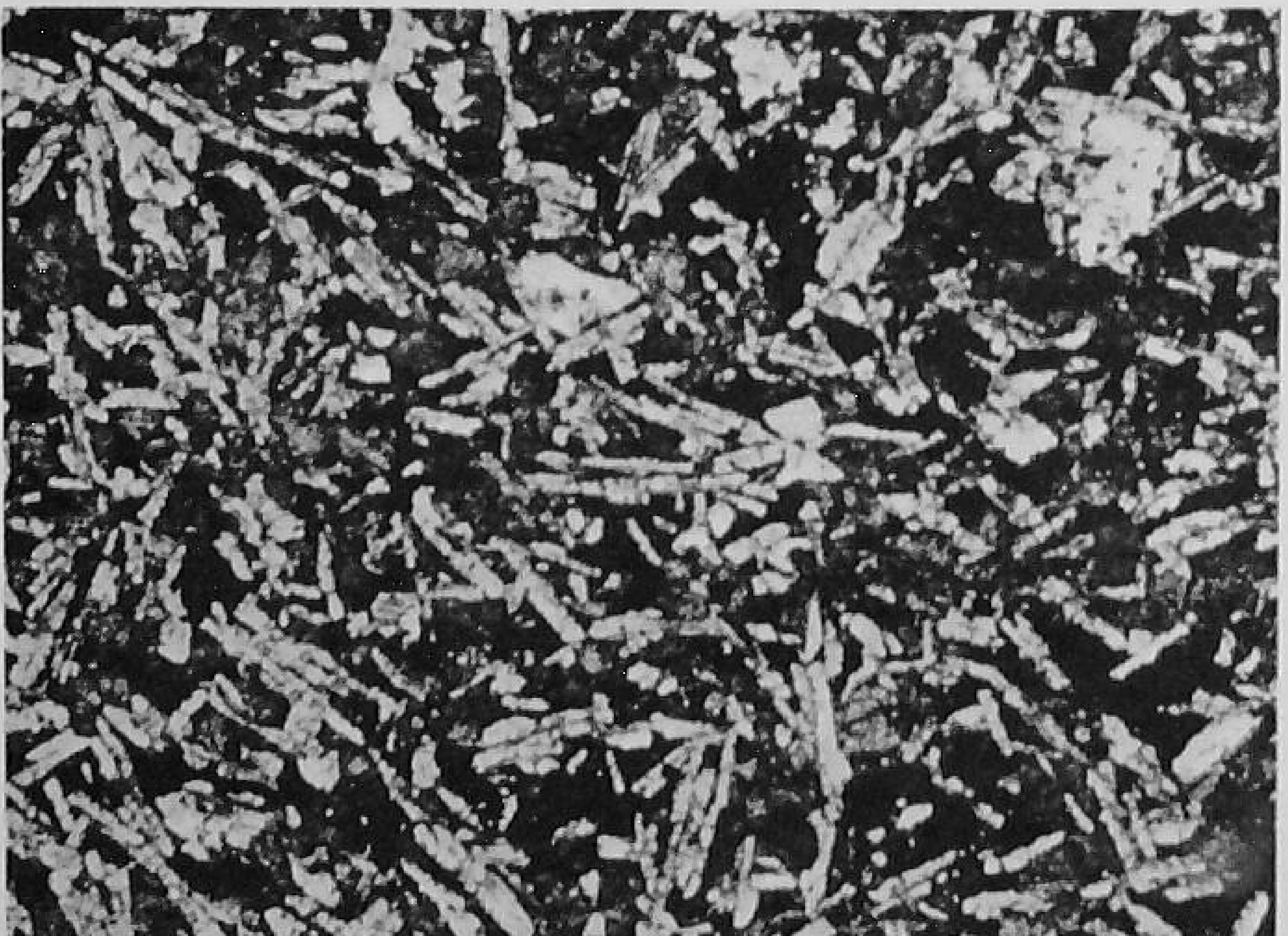
12. Key to the picture of Tintagel Castle and Haven. In the foreground the rocks are seen dipping eastwards. In the middle ground great slices of rock have been thrust over from the right. The planes of thrusting are indicated by the lines marked T. The skyline shows the Tertiary peneplain (P). The elevated position of the castle ruins (C) on both sides of the valley shows how much the valley has been deepened since the days of King Arthur.

13. Vesuvius in eruption, 1905.

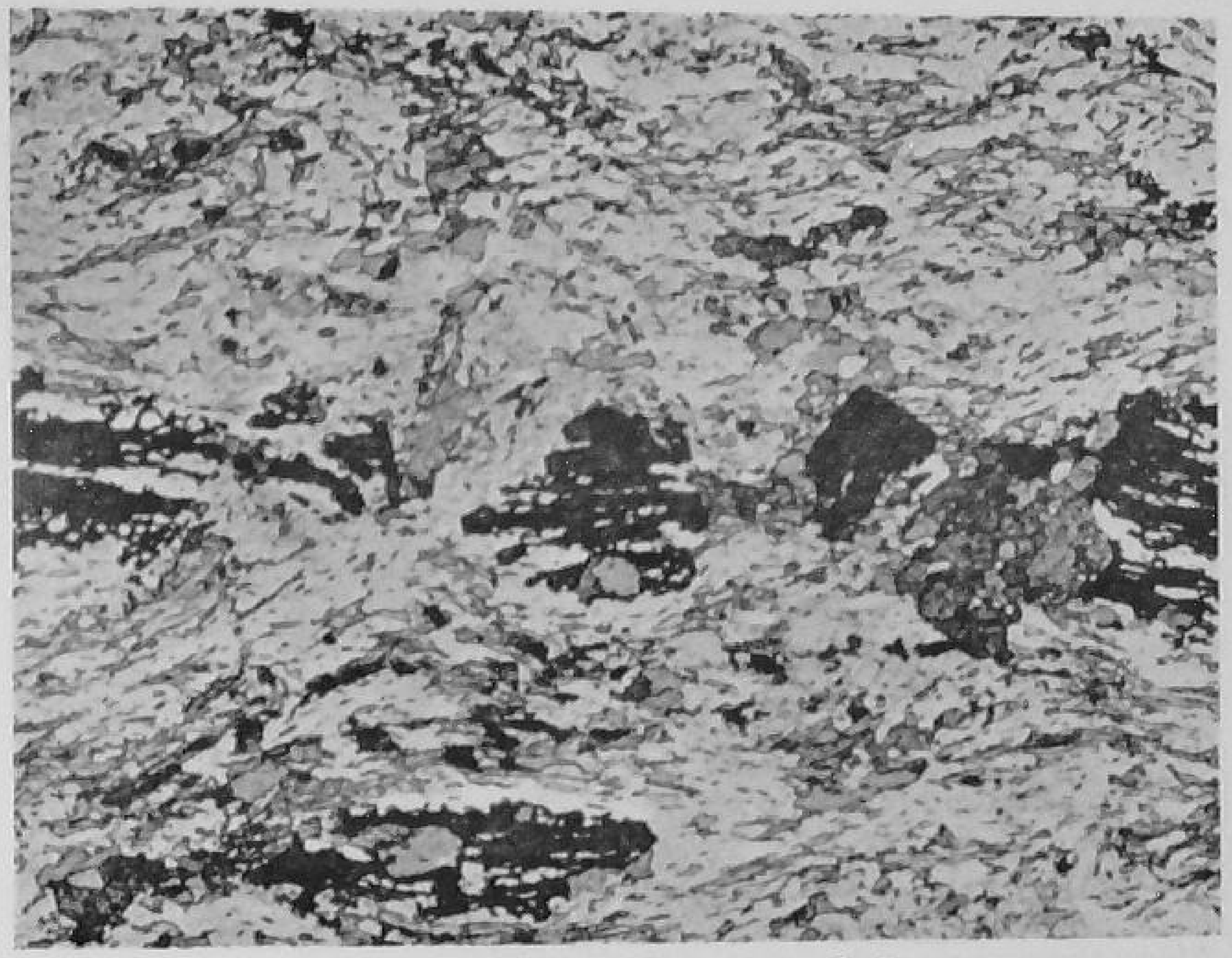
14. Arthur's Seat and Salisbury Crags, Edinburgh. On the left a sill of basalt-like rock forms Salisbury Crags. On the right the Lion's Head and Haunch show stumps of two volcanic necks.



15. Section of granite. Penrhyn, Cornwall.



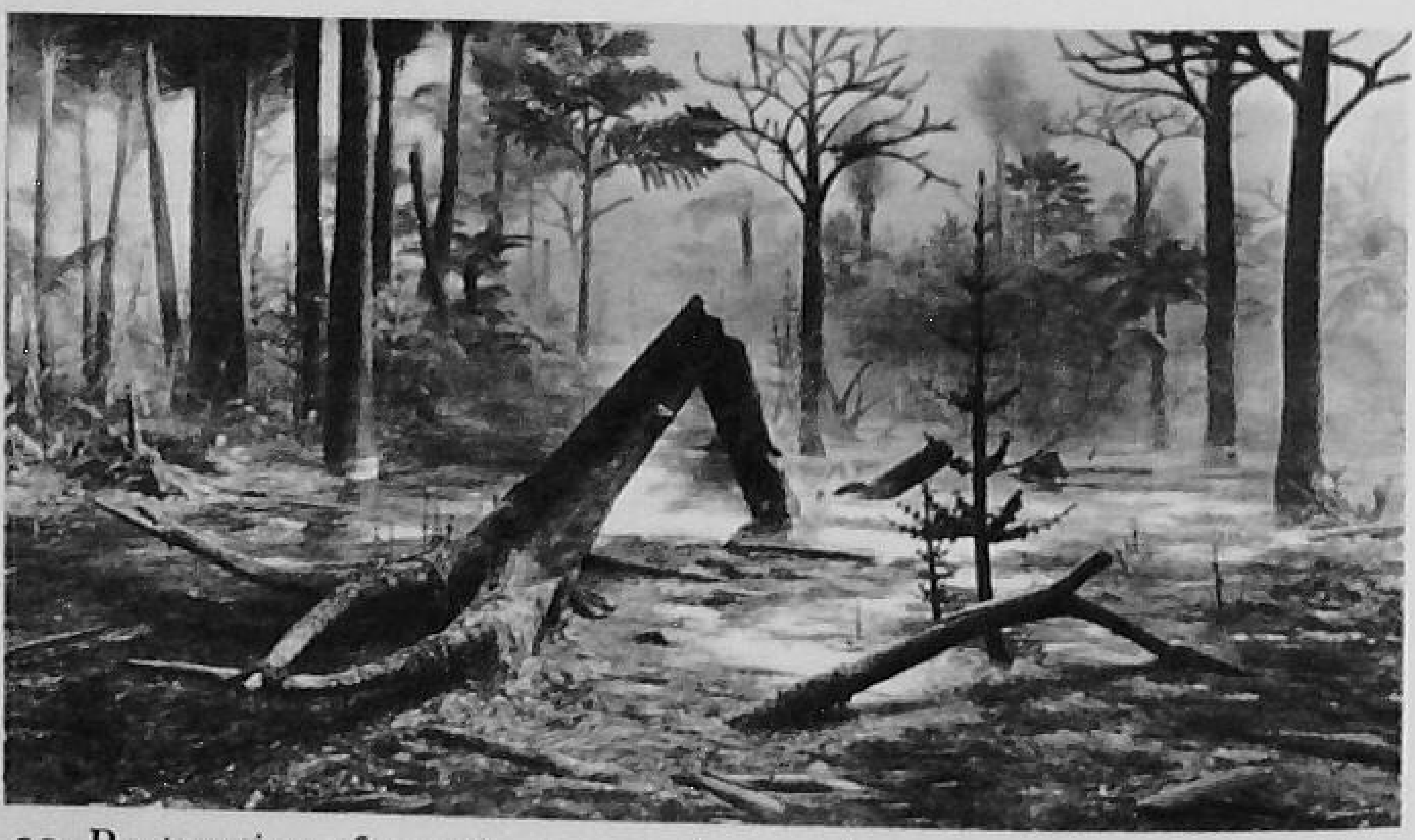
16. Section of basalt. Fusagill, Iceland.



17. Mica schist with garnets, Italy.

18. Granitization of gneiss. Brendeberge, Norway. The light veins mark the paths by which mineralizing fluids from granite have penetrated the gneiss.

19. Torridonian sandstone on Lewisian gneiss. Stoer, Sutherland. Along the skyline is the scarp of the Torridonian sandstone extensively cut up into isolated hills. This rests upon Lewisian gneiss which occupies the rest of the picture. Its hummocky surface is due to erosion by ice.

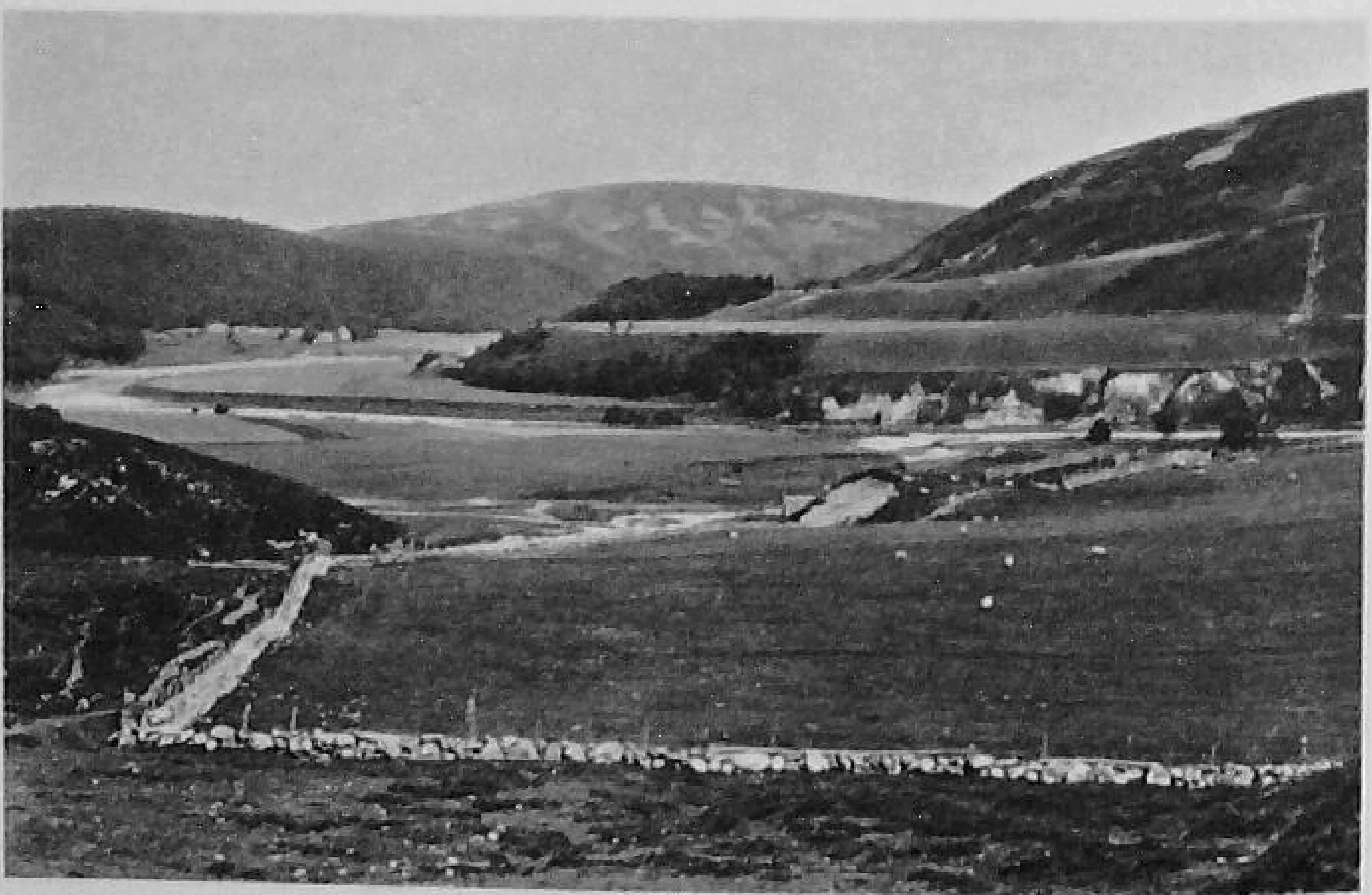


20. Restoration of a coal measure forest. Large trees: *Lepidodendron*, *Cordaites*. Small trees in the undergrowth: tree-ferns, *Calamites*.

21. Restoration of landscape in early Cretaceous times. The vegetation includes conifers, cycads, tree ferns, and horse-tails. The fauna includes various reptiles: *Iguanodon* in front; *Polacanthus* on the right; *Brontosaurus* in the water ; and a *Pterodactyl* in the air.

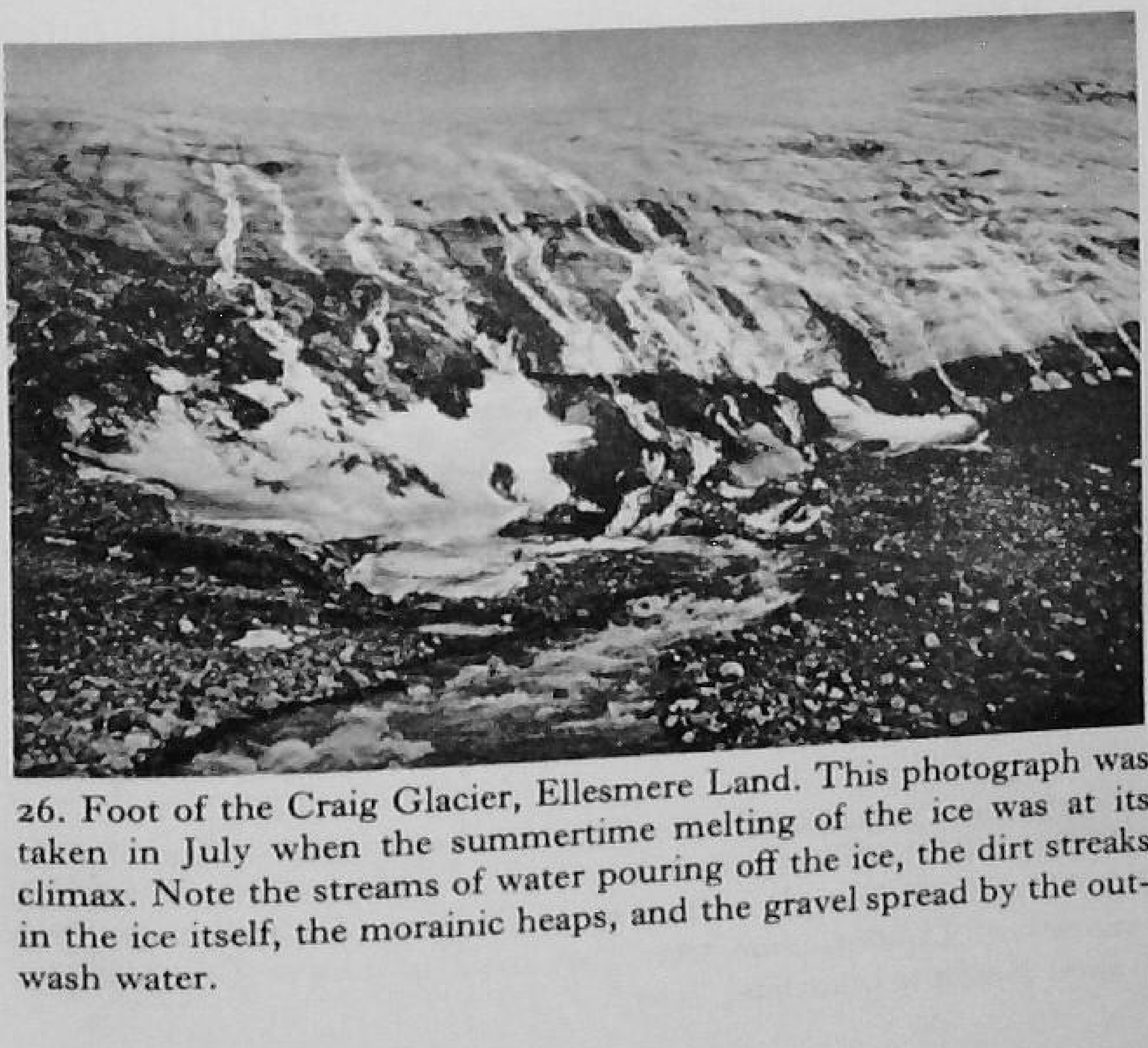
22. Restoration of a landscape in Tertiary times. The vegetation includes magnolia in flower (left), palm tree (left centre), ginkgo, oak, etc. Among the animals is *Hyrachotherium* (left) the very small ancestor of the horse.

23. Carding Mill Valley, Shropshire. A river valley in an early stage of development. Note the way in which spurs from opposite sides overlap.

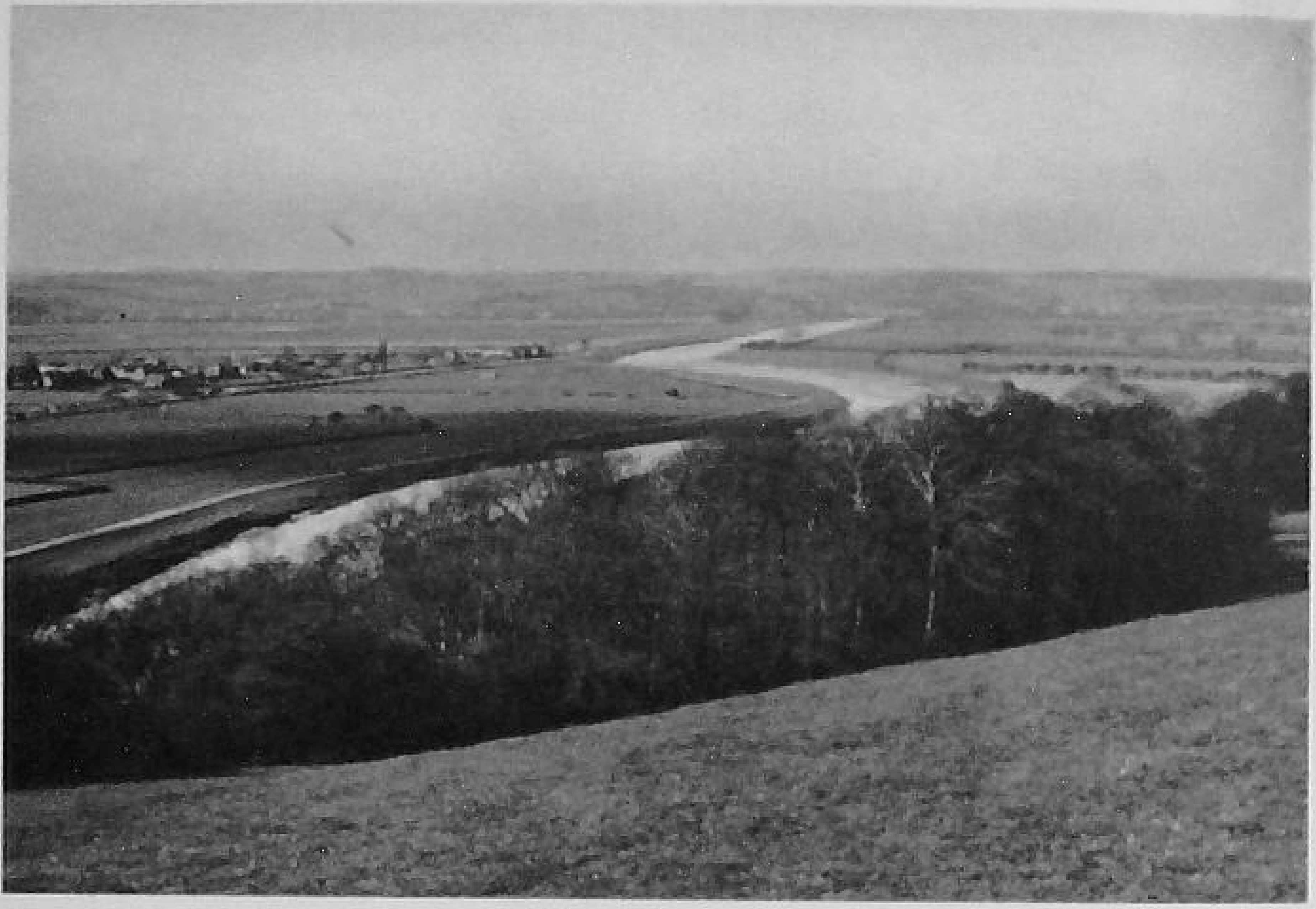


24. Terraces of the River Findhorn, Nairn. This succession of terraces was cut by the river out of deposits laid down by glaciers. It marks the stages in the lowering of the valley floor.

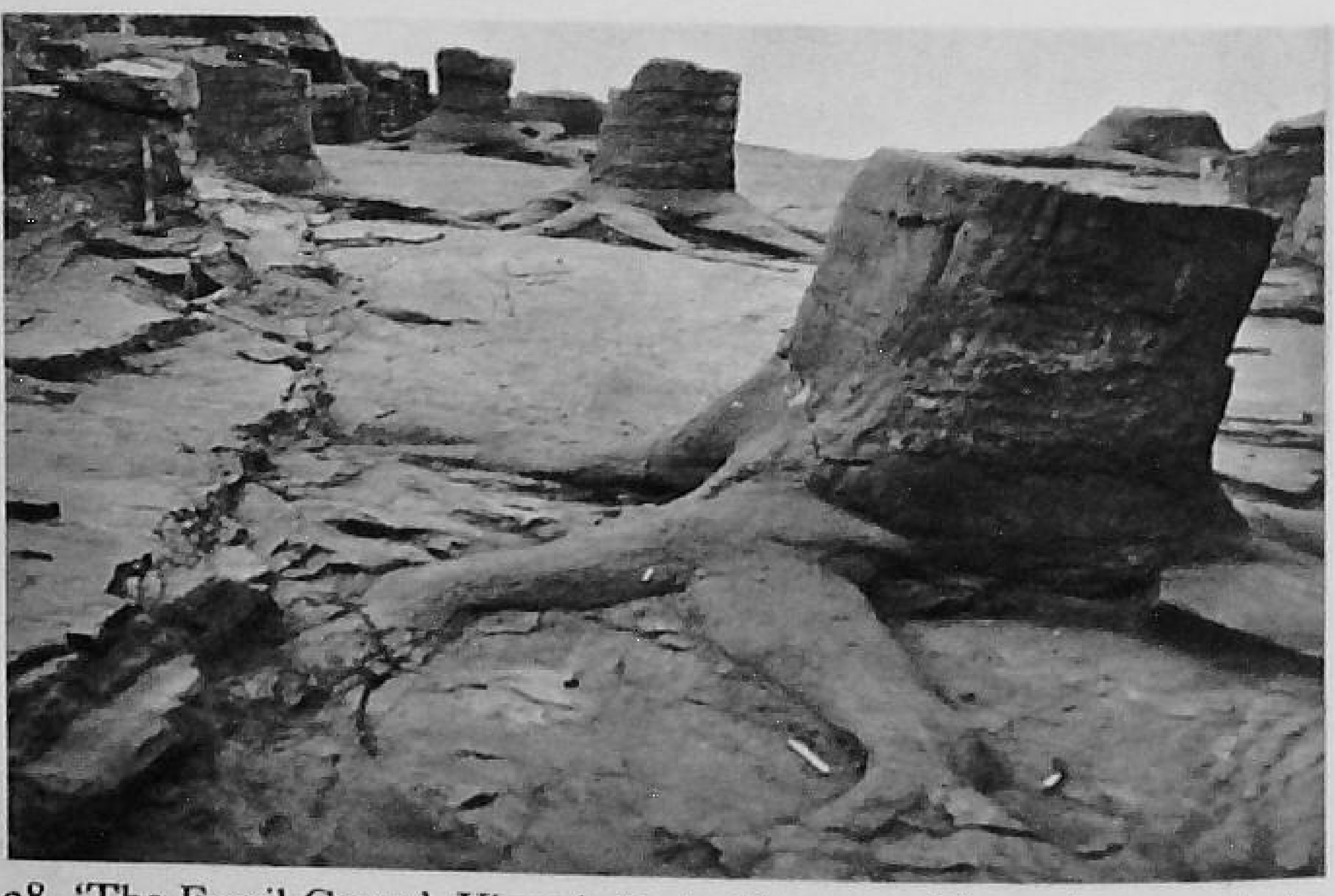
25. Diorama of an Alaskan glacier. Cirques filled with snow and ice are seen at the source of the glacier. Debris from the lateral moraines of tributary glaciers form long streaks on the surface. Numerous crevasses break up the surface near the end or foot of the glacier. The rocks along the valley sides have been rounded by ice action. Those forming the skyline have been shaped mainly by frost action.



26. Foot of the Craig Glacier, Ellesmere Land. This photograph was taken in July when the summertime melting of the ice was at its climax. Note the streams of water pouring off the ice, the dirt streaks in the ice itself, the morainic heaps, and the gravel spread by the outwash water.



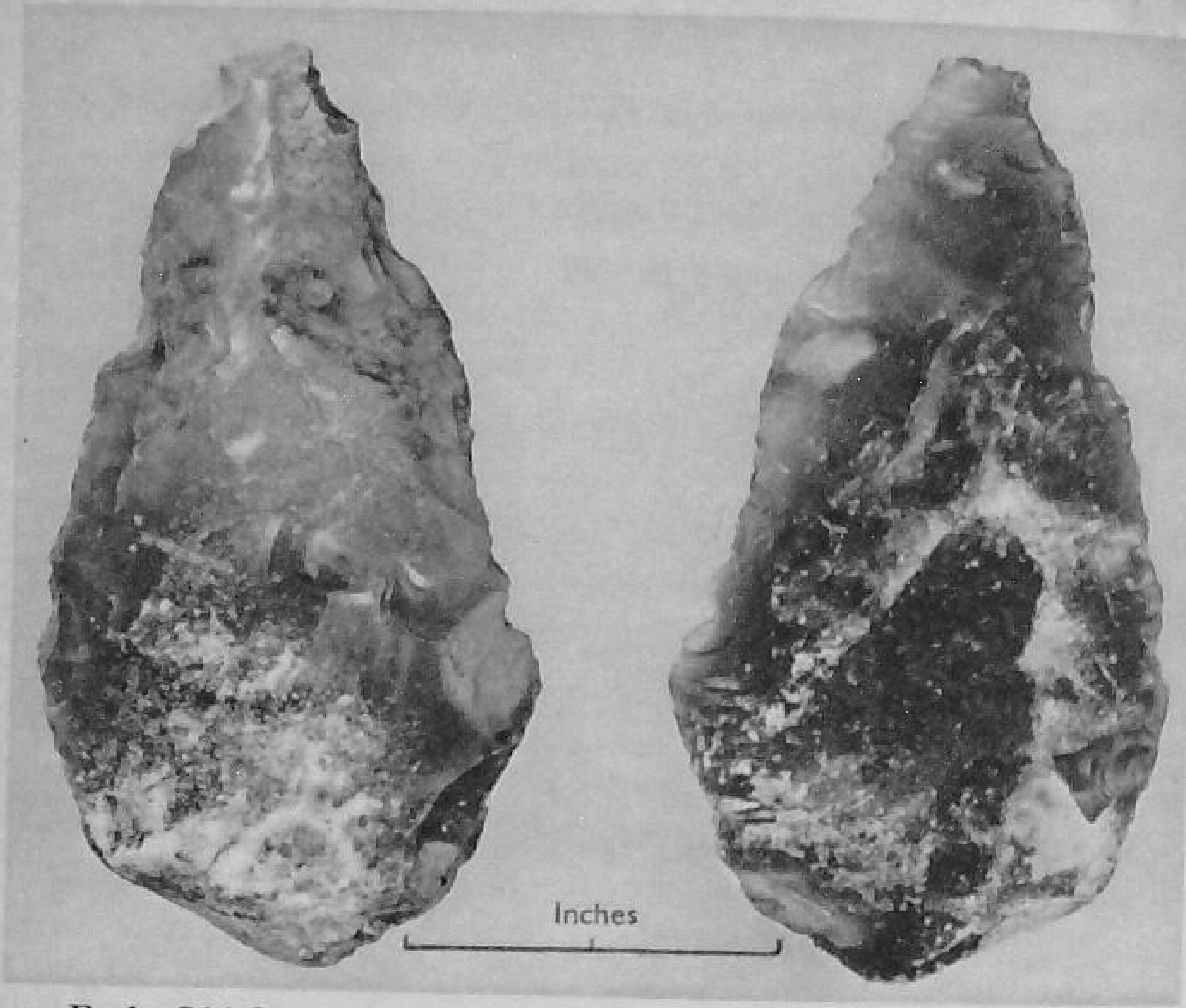
27. The Valley of the Trent near Nottingham. This trench-like valley was initiated by the summer flood waters which flowed along the margin of the ice which occupied the country south of the picture. The feature occupying the middle ground on the left is a terrace resulting from further excavation.



28. 'The Fossil Grove', Victoria Park, Glasgow. Natural casts of the stumps of *Lepidodendron* trees that lived in Lower Carboniferous times. Note the branching 'roots'.

29. The Avon Gorge, Bristol.

30. Wenlock Limestone from Dudley. Its weathered surface shows Silurian fossils, stone lilies (*Cyathocrinus*), and honey-comb coral (*Favosites*).



31. Early Old Stone Age implement, Lincolnshire. Middle Acheulian type. It had lain undisturbed for thousands of years on the spot where Palaeolithic man had dropped it.

32. Church Hole Cave, Cresswell Gorge, near Worksop, Nottinghamshire. This cave in magnesian limestone has two entrances. With other caves in the gorge it was inhabited by Old Stone Age and Middle Stone Age man at the end of the Ice Age.

differences in the appearance of the varves that were subsequently formed. De Geer put the date of this moment at 7912 B.C. The end of the Pleistocene and beginning of the Holocene may be dated at about 10,000 years ago from the present day.

In North America work was carried on along similar lines. Though conditions there, up to the present, have not proved so favourable for examining such complete sequences of varves as in Europe. Nevertheless enough has been done to indicate that the margin of the ice-sheet lay in the vicinity of New York about 16,000 years ago.

The extension of polar conditions into lower altitudes was accompanied by a corresponding shift of the temperate climatic belts equator-wards, and regions which now have dry conditions, such as South-east Europe and the Sahara, experienced pluvial periods or times of copious rainfall. These left behind them, when they passed away, their own characteristic kinds of deposits and types of erosional features. The study of these is still in its infancy.

While the continents were passing through this remarkable series of climatic changes, the seas and oceans were far from being unaffected. After all a continental ice-sheet is only water in a solid state, piled up in great heaps upon the land. The only source for the supplying of that water is the ocean. It is obvious, therefore, that in times of glaciation the surface level of the sea must have been lowered everywhere.

Records of such changes of level exist in the form of 'raised beaches'. Some of these are indeed old beaches that have actually been lifted up above sea-level. Others, however, are ancient beaches that have been left high and dry because the level of the sea itself has been lowered. Ancient beaches of this kind were first carefully studied in the Mediterranean, but they have also been found and investigated along the shores of the Atlantic, and in many other parts of the world. The close agreement between the results of all these inquiries leaves no doubt that each change of level was world-wide, and that a succession of such changes in sea-level has taken place within recent geological times.

Much water of ultimate oceanic origin is still locked up in the Arctic and Antarctic icefields; enough, in fact, to make a difference in sea-level of about 300 feet. It is because of this that terraces, which record former sea-levels are not now submerged but are exposed to view. These changes also left their impressions alongside estuaries and up the lower reaches of river valleys. Farther upstream they meet and overlap the present valley floor and fragments of earlier floors preserved on river terraces. In this way the records of climatic changes on land and the world-wide oscillations of sea-level are linked up with one another. The examination of these linkages will, no doubt, ultimately lead to the establishment of a sound correlation between the world-wide succession of ancient levels and the more localized events that took place upon the different continents. The result in the end should be a complete world picture of Quaternary history.

Another means of such a correlation has arisen recently out of laborious calculations that some astronomers and mathematicians have been making, during the last 150 years, upon the variations in amount of sunshine received by the earth at different times. The variations are associated with sundry astronomical disturbances that have occurred, such as deviations in the inclination of the earth's axis, 'wobbles' in its orbit at times when planets pass by and slow movements of the orbit as a whole. The times of conjunction and disjunction of these several disturbances can be calculated in terms of years. The effects for different latitudes on the earth's surface can also be ascertained. The results for the general latitude of the Pleistocene icefields have proved most illuminating. Plotted as a graph for the last 600,000 years the times of minimum reception of sunshine appear as four prominent peaks. The arrangement of these upon the graph exhibits a striking resemblance to that of the successive periods of glaciation. They also fall into an earlier and a later group, separated by a wide gap in which no such minimal peaks occur. This gap evidently corresponds with the main interglacial period. Within each of these two groups a similar but shorter gap occurs, which corresponds with the first and third interglacials respectively. The last peak

is subdivided into three minor peaks separated by two minor gaps. These correspond with the three phases and two interstadials of the last glaciation. These and other detailed similarities leave little, if any, doubt that the astronomical events which have been so carefully investigated have actually played a part, even an important part, in bringing about the remarkable series of climatic changes that took place during the Pleistocene.

In view of all this it is reasonable to accept the results of these calculations as providing a provisional basis for an absolute chronology for that period. According to this chronology the length of post-glacial time has been 22,000 years; the first and last interglacials each lasted 60,000 years, and the main interglacial lasted 190,000 years; the Pleistocene period as a whole lasted 600,000 years. The agreement of these results with the estimates made many years ago by Penck, which were based upon a quite independent set of facts and arguments, is indeed truly remarkable and increases confidence in both methods of approach to such problems.

25

THE STAGE AND THE ACTORS

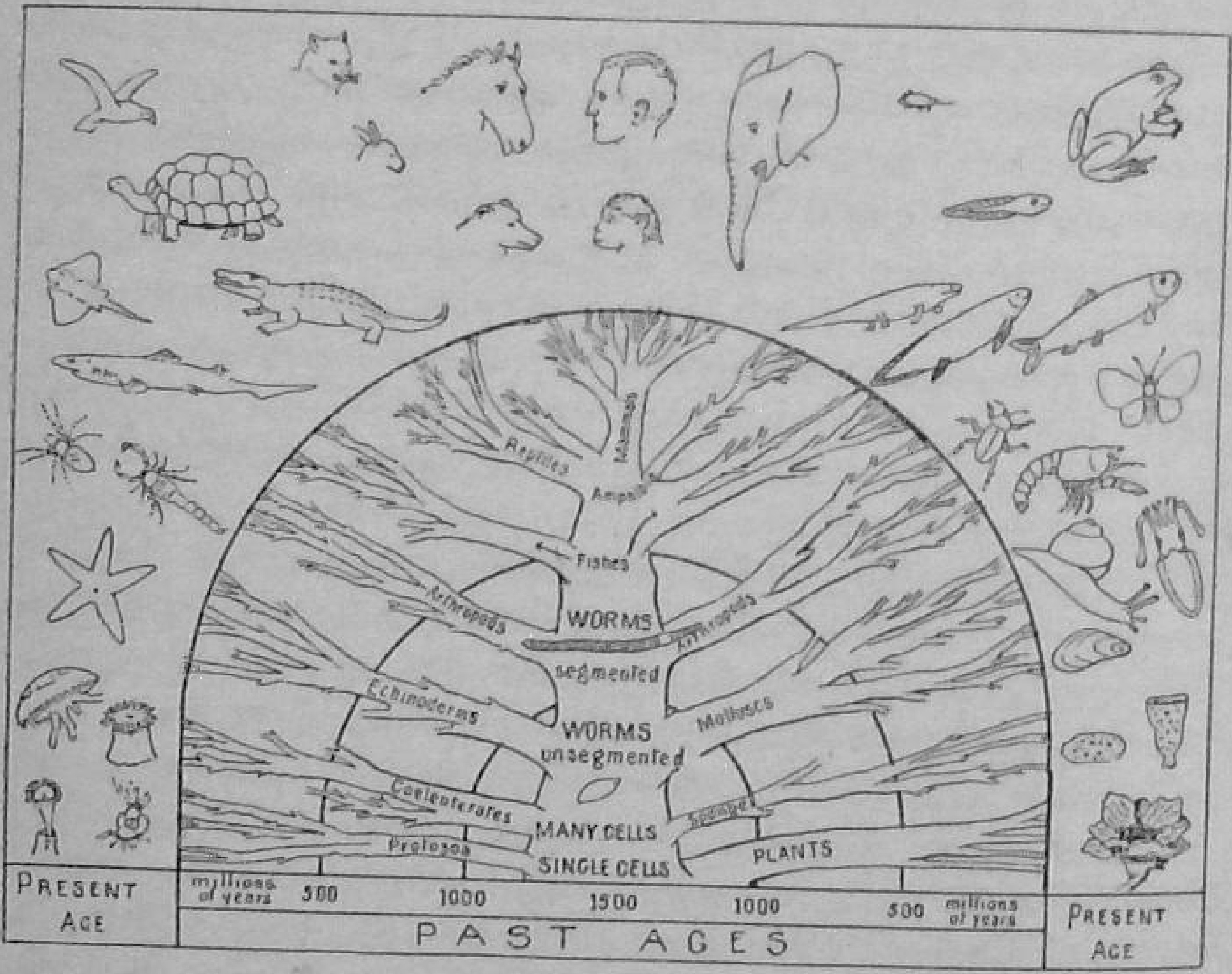


FIG. 10. PASSENGERS IN THE PROCESSION OF LIFE

'ALL the world's a stage' and on it there has been enacted the greatest known drama in the universe: the evolution of living things and of man. Hitherto we have been concerned with the laying of the foundations of that stage and the construction of its frame-work. We must now watch the painting of its scenery and the coming on of the actors. Before going out to meet the procession of living things on its arrival from its long journey

across the ages, we must pause to look into the composition of the present world picture; the last of a galaxy of scenes that have developed in beauty and complexity as they have followed one another in unbroken succession along the corridors of time.

On the physical side we have caught glimpses of a general principle which underlies the artistry of Nature; that great underlying mystery whom many have sought to define in a variety of different ways. Nature rarely destroys any scene completely, but preserves some relic from it which plays a part in the background of the present. Electrons from the original nebula are locked up in our gems or circulate in our veins. The vaporous and liquid stages in the story of our globe are reflected in the blue sky with its clouds, and in the restless sea. The Pre-Cambrian rocks, volcanoes, and mountains were worn down wholesale; but their remnants make up the great shield regions of the world, and their much travelled fragments are found as pebbles in our gardens. In like manner mementoes of each age have been retained while those portions of the scenic foundations that were destroyed have been reformed into new rocks and new features now placed against a background of old survivals.

This is all equally true for the world of living things. If it were not so the story of their past would have been for ever a closed book. Actual remains of plants and animals that lived ages ago have been found, more or less completely fossilized, in the rocks. Usually the soft fleshy tissues have perished, but the hard parts, the shells and bones, have been preserved. Sometimes, however, even these have disappeared, for water, percolating through the rocks, has dissolved their substance and only an empty cavity remains. Even so replicas of their shapes and markings may be obtained by making casts of the cavity. From these 'casts' much may still be learned about the original owner of the shell or bone. Sometimes all vestiges of the animal's body have gone. Nevertheless traces of its former existence are found in the form of trails left upon the mud, over which the creature crawled, or of footprints made upon the silt and sand when it passed that way.

Plant remains have usually changed considerably. The liquid

and gaseous constituents of their tissues have been dissipated and only a few details of form and structure have been preserved. Under exceptional circumstances, which will be described later, whole plants have been perfectly preserved, so that almost as much may be learned about those plants that lived many millions of years ago as if they had been growing in the fields and marshes to-day.

After this brief survey of the types of fossil evidence, upon which the following chapters are based, we may go out and meet the actors that have travelled in the procession of life on their arrival at the present.

What a crowd of passengers emerges! Animals and plants of many different types, each with its own tale to tell of its journeyings, of its homes in the sea or on the land, underground or in the air. But before we can begin to listen to their stories we must be introduced to them, find out who they are, what they are like, and learn to recognize them.

We ourselves belong to that procession. As men and women we are distinguished from many of the other passengers by our upright attitude of body, standing on two feet, and equipped with two of nearly everything, legs and arms, hands and eyes, placed symmetrically on a central head and trunk. These are all supported on a strong framework of bones, hung upon a central axis made up of skull and backbone. Most of the other passengers that first catch the eye go about like children running on all fours with their hands as well as feet upon the ground – dogs, cattle, tortoises, frogs, all seemingly so different and yet, on closer inspection, all are seen to be built on precisely the same plan as ourselves. On that account the sober-minded scientist puts them together in a caravan labelled 'Backboned animals' or the *Vertebrata.* He even puts alongside of them the salmon and cod for, though they differ from the rest in having no arms and legs, they also have two pairs of limbs in the form of fins.

Looking beyond these vertebrates our attention is caught by very small and very different creatures some of them buzzing and flitting around in the air; wasps, butterflies, and other insects. These also are equipped with eyes and limbs arranged

symmetrically in pairs. In them, however, there are three pairs of legs and often one or two pairs of wings, all likewise attached to a central head and body. These are all supported by a framework which is outside and not inside the body, consisting of a hard coating which fits every part like a skin. This rigid coating is divided into a series of ring-like sections with flexible joints between. The covering of the legs is also made up of segments similarly jointed together. In the garden or out in the fields we come across other creatures whose bodies are covered, segmented, and jointed, in the same way, spiders with four pairs of legs, brown wicked-looking centipedes, and black curled-up millipedes with hundreds or, apparently, thousands of legs. These last have long bodies with many segments, each carrying legs attached to the underside.

It seems a far cry from butterflies to crabs and lobsters; the one flitting about in the air, the other scrambling about on the floor of the sea. Nevertheless, structurally they have much in common – the two-sided symmetry, the external framework or skeleton neatly fitting over every part of the body, yet wonderfully flexible. In all these respects they are strikingly different from ourselves and the other vertebrates. The caravan into which the systematic scientist puts them all is labelled *Arthropoda* (*arthron* = joint, *podos* = foot): a term which refers to the many-jointed structure of the legs.

Another familiar creature in the garden is the earthworm, a long-bodied animal with two-sided symmetry. Its body is without a supporting framework either inside or out, and is, therefore, quite soft. Like the centipede, it is divided into many ring-like segments. Indeed it is not difficult to imagine that, if it were endowed with a hard coating and many short legs, it would be easily mistaken for one of these creatures. Earthworms all seem to be nearly alike. They are, however, strangers in strange surroundings for all their relatives live in the sea, and exhibit an endless variety in form, colour, and size. Some live in the mud, others live in tubes constructed out of bits of shell and grains of sand, or made of lime secreted by the worm itself. Others again are agile, free-swimming, rapacious creatures, provided with sharp hook-like jaws with which they attack

more feeble folk. Much less familiar to the fisherman, or to the juvenile naturalist hunting in the rock pools, are the small flat-bodied unsegmented worms that hide under stones. All these lowly worm-like creatures have come along in the caravan labelled *Vermes*.

Another familiar, almost repulsive, creature in the garden is the slug. It also has two-sided symmetry and a soft but unsegmented body. Along with its relative, the snail, it is so much more highly organized than the worm that it can, in the dark, deliberately seek out and raid the gardener's most succulent crops, and then spend the daytime slumbering in some undiscoverable hiding-place. Like the earthworms, slugs and snails are strangers in a strange land. They have an even greater multitude of relatives of high and low estate living in the sea – winkles, whelks, mussels, oysters, cuttlefish, and the octopus. All these have features in common which distinguish them from the other living creatures and are placed in a separate caravan labelled *Mollusca* (*mollis*=soft).

Varied as are the forms that live on the land, the natural home of living things is in the sea. This teems with a still greater variety of types that have no representatives breathing air and living on the landscape.

One small but important group of forms is sometimes called the *Molluscoidea* because they bear a striking resemblance to those mollusca which, like cockles and mussels, have bivalve shells. The planes of symmetry, however, of the two types are, so to speak, at right angles to one another. That of the cockle passes between the two valves of the shell which therefore lie on either side of the body. But in these animals it passes through the middle of each valve. At the tip of one valve there is usually a hole through which, during life, a fleshy stalk protrudes. By means of this the creature is anchored to some rock or stone. Hence the name of *Brachiopoda* (*brachion*=arm) is more frequently used than Molluscoidea for this type of animal. They are also popularly known as 'lampshells' because of their resemblance to a Roman lamp, in which the wick represents the fleshy stalk.

Distantly related to the brachiopods are the *Polyzoa* (*poly*=

many). As this name implies, these tiny creatures lived in dense colonies. Each individual is enclosed in a separate little chamber built of horn or of lime. The whole colony has often either a mossy or a leaf-like appearance.

All the creatures dealt with so far are alike in having a two-sided symmetry. But there are others that have a many-sided or radial symmetry. These include the starfish and sea urchin so frequently found stranded on the beach at the sea-side. Their bodies are supported by a stout framework which appears to lie outside the body, but is really imbedded in its fleshy outer covering. The framework may be like a network of limy rods or a mosaic of limy plates. The animal moves about by means of a multitude of 'tube feet'. These are fleshy tube-like extensions of a remarkable hydraulic system within the body which, by pumping water into the tube, extends it or, by withdrawing the water, retracts it. At the end of each tube is a sucker-like concavity by which it can cling on to some object and so pull the animal along. The surface of the body is usually armed with innumerable spines, sometimes thin and pointed, sometimes blunt and club-like. The name on the caravan for these creatures is, appropriately, *Echinodermata* (*echinus* = hedgehog, *derma* = skin).

Looked at dispassionately the types of creatures so far mentioned may be said to belong to approximately the same grade, neither higher nor lower than one another. Within each caravan, however, there are higher and lower members. The highest members of any one group can give points to those of another. 'Go to the ant, thou sluggard, consider its ways and be wise.' Those words of the ancient sage imply that the highest of the arthropods are in some respects comparable with man himself. Mr Wells in his book *The War of the Worlds* chooses as the Martian equivalent of man, the Octopus, the most advanced member in the molluscan caravan.

The next caravan in the procession may, for our purpose, be described as the 'Lowly Animal Caravan'. It houses a great multitude of small and often very minute creatures which differ from one another more than do men from worms. The highest among these are the jelly-fish and sea anemones. They

and their companions resemble the echinoderms in being radially symmetrical; but they have no skeleton or supporting framework. On the contrary even the flesh itself has so little substance that when a jellyfish, stranded on the beach, dries up, all that is left is a delicate film. Some of the sea anemones, called coral polyps, extract lime from the sea-water and use it for erecting pedestals or corals upon which they stand.

Next come the sponges, often without that regularity of form we have noted in all other animals. They possess a supporting framework made up of lime, or silica, or a silky substance such as that of the once-familiar bath sponge.

Last of all come very minute creatures whose bodies in each case consist of a single speck, a cell, of living substance or protoplasm. These creatures are ubiquitous. They inhabit the surface waters of the sea in teeming millions. Many secrete exquisite shells of lime (Foraminifera) or of silica (Radiolaria) so small as to be just visible to the naked eye. These single-celled animals are spoken of collectively as the *Protozoa*.

Arriving with this procession of animals is another cavalcade of living things which, through the ages, travelled alongside them by another but parallel route. At all stages in the journey they have provided a living scenic background in front of which the animals have peeked and preened and played their parts. In that background, as we see it to-day, are flowers and grasses, bushes and trees. Mingling with these are mosses and ferns. Spreading themselves shyly on tree trunks, on dry rocks and damp soils, are the lichens and green algae. In the sea these last show up boldly as brown, red, and green seaweeds, some of which, such as *Laminaria*, almost attain the stature of trees. Others again imitate corals and secrete masses of lime.

One amazing fact, revealed by means of the microscope and by the delicate technique of the student of living things, is that even the most advanced member of each caravan starts life as a single cell, a single speck of living protoplasm. In each one this cell divides and subdivides forming, at first, a hollow sphere of cells. One side of this becomes tucked in like a collapsed rubber ball, thus assuming the shape of a cup or a deep beaker, consisting of an outer covering and an inner lining of cells. The

rim of this narrows down to a relatively small opening. At this stage in its growth the animal closely resembles the Hydra or the sea anemone in basal plan of structure, for their bodies also consist of only two layers of cells. In the outer layer the several cells become modified to serve different functions. Some are sensitive to heat and cold or to contact with surrounding objects. Others contract or extend and serve the purpose of muscles. In the inner layer the cells are modified to secrete juices by means of which food may be digested. The

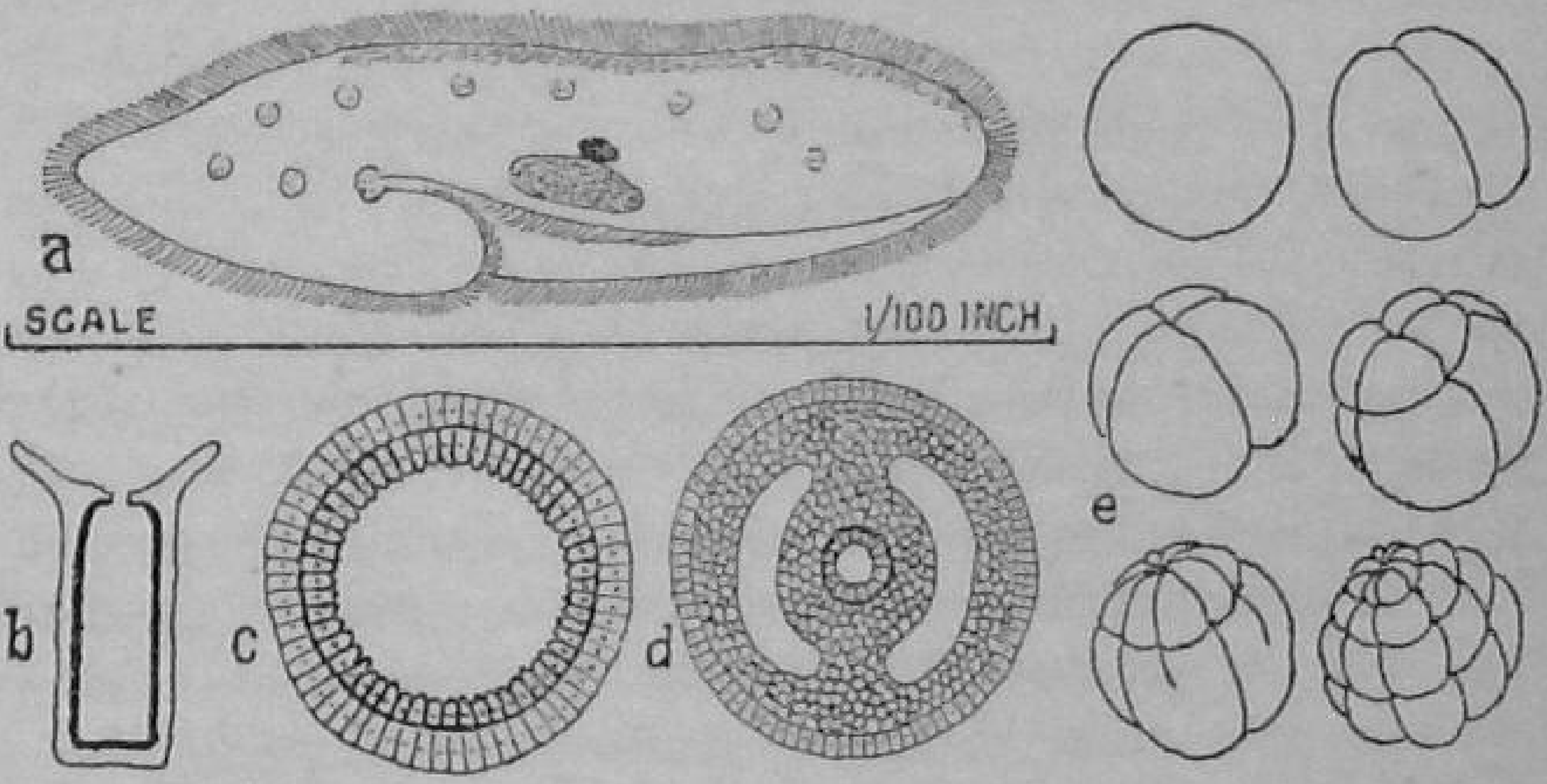


FIG. 11. GRADES OF STRUCTURE AMONG ANIMALS

Diagrams illustrating the basal grades of structure among animals. (a) Slipper animalcule – a single-celled animal; note the oval nucleus, and the small size of the animal. (b) Vertical section of a hydra with mouth and digestive cavity. (c) Transverse section of the same, on a much larger scale. The body is made up of two layers with many cells. (d) A similar section of a worm showing the outer and inner layers of cells separated by a mass of additional cells enclosing a cavity, the body cavity or coelome. (e) A series of drawings showing the earliest stages in the development of a frog, starting with a single cell which divides into two, then four and so on indefinitely

cavity enclosed by this double wall thus acts as an enteron or digestive cavity, hence the name *Coelentera* (*koilos*=hollow, *enteron*=intestine) for this section of animals.

During the development of a worm these two layers of cells become separated by the growth of another and much more bulky lot of cells from which the main mass of the body is produced. The presence of this third, more massive layer of

cells differentiates all other animals from the Coelentera and paves the way to that very wide diversity of form and structure sketchily depicted in the earlier part of this chapter.

The fact that all the higher animals, in their individual development, start as single cells which divide into many cells arranged first into two and then into three primary layers points to the Coelentera as their very early ancestors and beyond them to the Protozoa. These last must have been the earliest inhabitants living on this planet.

26

PAINTING THE SCENIC BACKGROUND

As mentioned before, the great abundance and variety of living things in the sea to-day points to the sea as their original home. This is strongly supported by the testimony of the rocks, which shows that the sea teemed with life long before the land first became inhabited in Middle Palaeozoic times. It is interesting to note, in passing, that though many types of animals live in the sea, only a few are represented on the land. With plants the reverse is the case, for in the sea only the lowliest types, such as seaweeds, are found, but there is a wonderful exuberance and variety living on the land – algae, mosses, ferns, tree ferns, pines, and flowers. The student of fossil plants, however, labours under a grave disadvantage. Owing to their branching straggling habit, plants are rarely if ever preserved as a complete whole. Their remains are usually fragmentary, like woodland débris.

The evidence for the existence of marine plants in Pre-Cambrian times is scanty and indirect, for most of the rocks have been crushed and metamorphosed in such a way as to destroy fossilized remains. Nevertheless beds of graphite, some of which are of vegetable origin, have been found in the rocks of the Scottish Highlands, and of the Baltic and Canadian shields. Again, as already seen, some seaweeds called corallines cloak themselves in lime extracted from the water. Considerable

masses of Pre-Cambrian limestone seem to have been built up in this way by algae of yet lowlier grade than seaweeds. Later, in the Palaeozoic rocks, impressions and actual remains of seaweeds have been found.

As for the land, it is most unlikely that evidence will ever be forthcoming to show that the lowliest algae found a home on the bare rocks of the Pre-Cambrian landscape. The possibility that they could have done so is suggested by the incrustations of green algae and of yellow and grey lichens to-day upon the barren surfaces of old stone walls, and of the precipices and rocky slopes among the mountains.

It is not until we come to the rocks of Silurian and Devonian ages that fossils of genuine land plants are preserved. A century ago Sir William Dawson discovered such remains in the Lower Devonian rocks of Canada, but, apart from the shape of the plants, these fossils exhibited very little of their detailed structure. In 1917 a fortunate discovery, made at Rhynie, in Aberdeenshire, was announced. Here a chert was found, in the Middle Devonian, which proved on examination to be a bed of peat preserved in silica. Many of the plants it contained were closely allied to those found by Dawson. These, however, were so exquisitely preserved that thin slices of the chert, examined under the microscope, revealed the minutest details almost as clearly as if they had been collected living from the fields and marshes of the present day.

Among the plants thus brought to light was one called *Nematophyton*, remains of which had already been found in Silurian rocks. This plant resembled the seaweeds, especially that large form known as *Laminaria*, familiar as a common object on beaches after rough seas. Its thick stem and broad flat tattered end sometimes attracts the notice of little children who pick it up and wave it like a flag. It is the largest of the seaweeds, and in deep water may grow to a height of 60 feet. But *Nematophyton* seems to have been even larger, for its stem increased in thickness to as much as 2 feet. Now the Rhynie chert is a fossilized fresh-water peat that was formed far inland, many miles away from the sea. Here then was a seaweed that had survived isolation from the sea under fresh-water

conditions. Was this an attempt on the part of these lowly plants to conquer the land? If so it was a failure.

The majority of the Rhynie plants were true land plants, but of much simpler type than exists to-day. They were closely related to *Psilophyton* which had already been discovered and described by Dawson. This had a creeping stem or rhizome

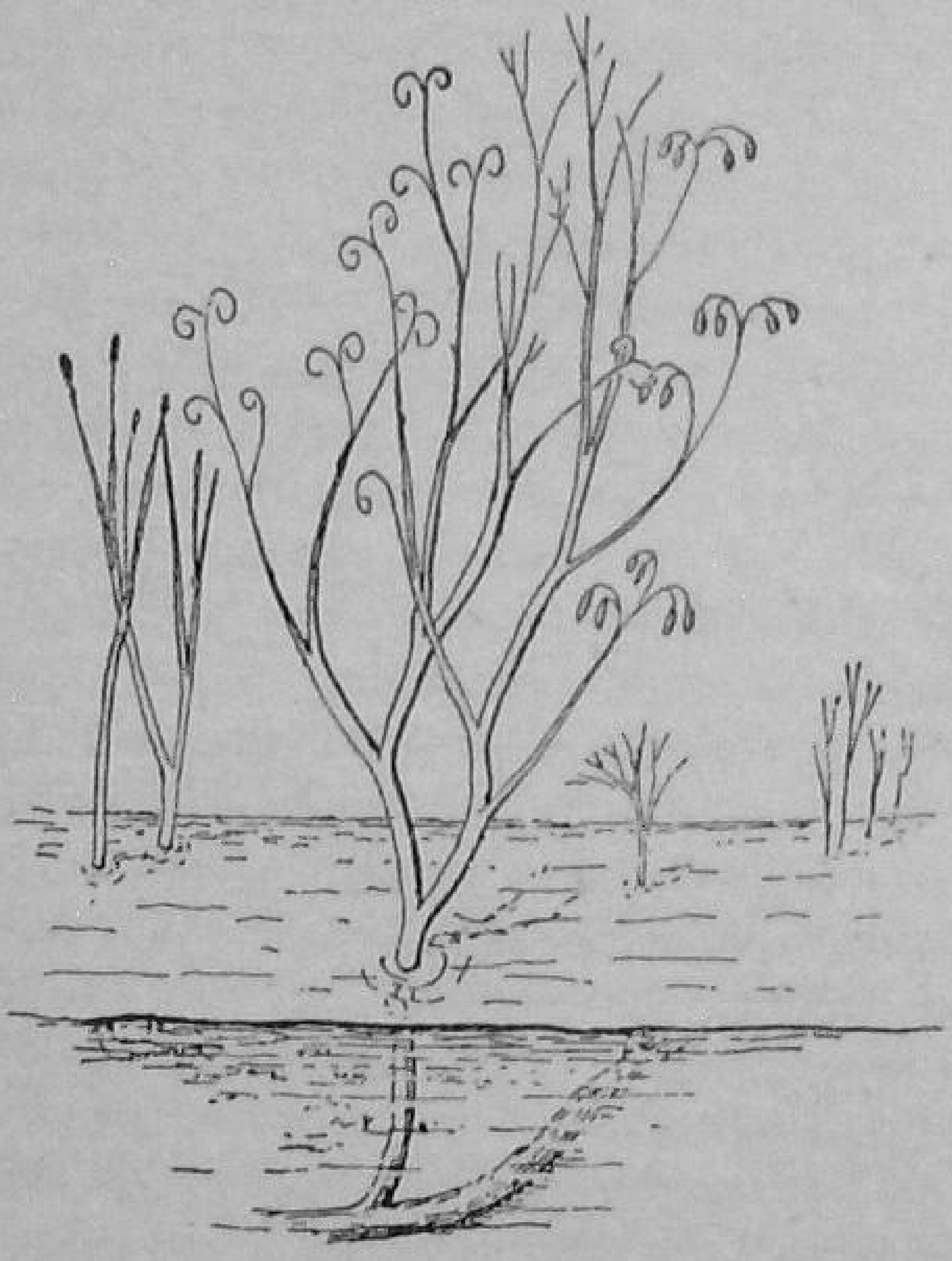


FIG. 12

Psilophyton and *Rhynia*, two representatives of the ancestral stock of land plants (Based on Dawson, Kidston, and Lang)

lying along the ground from which, at intervals, erect shoots arose a foot or more in height. At the top each of these carried a cluster of branches produced in a simple forking fashion. The tips of some of them curled like the pointed ends of young fern leaves. Those of others were swollen and enclosed a number of spores. Thin sections of the chert show that at the centre of

each branch there was a compact axis made up of tubular vessels with thickened walls. This axis or *stele* served the double purpose of carrying water and sap, and of providing a stiff internal support for the erect shoots. The plant had neither roots nor leaves, but the functions of the latter were performed by the shoots. These had upon their surfaces small pores or *stomata* by which carbon dioxide for food could be taken in from the air, while moisture and oxygen could be passed out from the plant.

The chert yielded a score or more genera of plants allied to *Psilophyton*. These are referred to collectively as the *Psilophyton* flora, and are of outstanding interest, because they represent the ancestral stock from which descended all those vascular land plants which now carpet and beautify the landscape. For a long time mosses were regarded as representing the ancestors of plants, but this Rhynie flora has displaced them from that proud position. The precise contribution of mosses to the story of plant life has still to be discovered.

Within the *Psilophyton* flora are genera whose features anticipate the major modifications seen in the Carboniferous plant world. This latter was so luxuriant, and its individuals so sturdy, that they grew together in extensive forests. Their accumulated débris provided material for producing those invaluable sources of coal that have played so vital a part in man's industrial development during the last two centuries.

Let us look more closely at some of the types which grew in those forests. Fortunately diminutive survivors still live in our midst. Nestling among the moorland grasses is the stag-horn moss *Lycopodium*; or, hiding shyly under table decorations, is *Selaginella*. These insignificant plants are the direct descendants of a race of giants that dominated the marshes and the hillsides of the Carboniferous landscape. Chief among these was *Lepidodendron* (*lepis*=scale, *dendron*=tree), a tall tree with a trunk that was at times 3 or even 4 feet thick. This consisted mainly of soft tissue supported by a strong woody stele occupying one-tenth of its diameter. At its top the lofty trunk forked and reforked into a bushy mass of branches and twigs, having the same general plan as that already seen in *Psilophyton*. In

Lepidodendron there was a complete covering of simple spear-shaped leaves. At the tips of some of the twigs, as in *Lycopodium* and *Seleginella*, the leaves were clustered together in a manner not unlike a fir cone, and each leaf carried a sporangium or capsule filled with spores. In springtime the sporangia burst, releasing the dust-like spores which were blown by the wind in golden clouds over the woodlands. A few dropped on spots where they could grow and ultimately produce new trees. Many of them fell into the waters of swamp and marsh where the woodland débris was accumulating and forming peat; the first step towards conversion into coal. These spores made a not inconsiderable contribution for to-day some coals are described as spore coals.

Lepidodendron was so called because its bark was covered with diamond-shaped scales arranged spirally. *Sigillaria*, another forest tree of comparable dimensions, had its bark traversed by vertical grooves which separated rows of similar scaly marking. At their bases both types of tree gave off branches by means of which they were anchored to the ground. These carried numerous short roots. Fossil fragments of these branches are common and are distinguished by the presence on the surface of little pits which mark the points of attachment of the roots. Before the real nature of these branches was understood they were thought to belong to a third type of tree and were called *Stigmaria*.

Revisiting the present-day scene once more, we find in many patches of waste ground little plants resembling Christmas-trees. They may be as much as 3 feet high, and are known as horsetails or *Equisetum*. A close inspection of the main stem shows that this consists of a series of segments each of which has a finely fluted surface. Branchlets grow out in radiating fashion from the junction between the segments. These plants are the survivors of another race, represented by small trees known as *Calamites*, which played a prominent part in the Carboniferous forests.

A more abundant and much more familiar element in our present flora are the ferns, which thrive mainly in the undergrowth of the woodland. They occupied a similar but more

prominent place in the Carboniferous forests. A few minutes' search on any colliery tip-heap will often suffice for an amateur collector to fill his bag with fossil fern leaves, and his mind with a sense of the importance of the place filled by these plants in those far-off days.

One very striking fact about these leaves is that they sometimes bear seeds. Other plants even in Devonian times produced imperfectly developed seeds but on these fern-like plants almost perfect seeds have been found. Perfection in this case consists of a combination of structures that enabled the plant to reproduce its kind and live on really dry land far from swamps and marshes. As long as plants reproduced by means of spores they were tethered to such wet situations, for a spore is not a seed. When a spore settles on damp ground it does not give rise forthwith to a baby fern, but to a tiny plate-shaped plant having neither roots nor leaves. This is endowed with sex organs and is, therefore, able to form egg cells and spermatozoids. The latter cannot go to the egg cell and fertilize it unless both are covered with water through which the spermatozoid can swim and thus reach its destination. A seed is much more complex than a spore. Fundamentally it is a sporangium enclosed in thick protective coverings and containing one female spore. Within this the tiny plant that bears the sex organs and egg cells is retained and nourished by the parent plant. When an egg cell is ripe the male spore, carrying the spermatozoid, is borne to it, like pollen, by the wind. The egg cell is fertilized and a minute seedling is formed which at first is also nourished by the parent plant. Thus the need for a covering of water at this strategic point in the life-cycle of the fern is eliminated. Ferns had thus become genuine land plants capable of growing and reproducing almost anywhere on the land.

Those primitive seed-bearing plants are represented to-day by the tree-ferns, cycads, which grow in comparative abundance in sub-tropical forests.

Living alongside the rich variety of trees that grew in the late Devonian and Carboniferous woodlands was *Cordaites*, a small tree with spirally arranged branches. The fossil remains of its leaves are common, but they have not that attraction for the

eye of a collector that 'fossil ferns' possess. They were like giant grass leaves with straight sides and parallel veins. *Cordaites* was also a seed-bearing plant and gave rise to that great race of familiar trees known as conifers. In these the seeds lie single or in pairs on the surfaces of special scale-like leaves, which are clustered together round the ends of twigs in the form of cones.

Genuine conifers were represented in the Permian by *Walchia* and in the Trias by *Voltzia*. This latter was a primitive edition of *Araucaria*, the monkey-puzzle tree, which plays a prominent part in the forests of Chile and was introduced as an exotic into English gardens in the nineteenth century. There it may still be seen standing erect with temptingly arranged branches, covered with sharply pointed leaves that defy the most ardent boy climber. In Jurassic times this type, together with other conifers, became abundant. In Cretaceous times the mammoth red pine, *Sequoia*, appeared in Greenland. Thence it travelled south and to-day lives on the moist slopes of the Pacific coast-line of the United States and Canada, where it attains a stature of 300 feet. During the Tertiary era conifers increased still further in numbers and extended their range over the earth. Towards the end of the Tertiary, however, they began to decline, but to-day they still contribute considerably to the temperate forests and woodlands.

All the seed-bearing plants so far considered are referred to collectively as *gymnosperms* (*gymnos*=naked, *sperma*=seed) because their seeds are carried on leaves or scales in an unprotected or naked state. One more gymnosperm should be mentioned. It is the maiden-hair-fern tree, *Ginkgo*, the sacred tree of the Buddhists. This type also has a very long history for its earliest ancestors lived in company with *Cordaites* in the Carboniferous forests. Though it became a conspicuous feature in the Jurassic scenery, it never exhibited any marked tendency like that seen in the conifers, to produce a wide variety of types. Since then it has declined and owes its survival during the last 2000 years to the fact that it has been cultivated in Buddhist gardens.

Though pines, cedars, and other gymnosperms have a beauty

and stateliness of their own, they lack colour. The coniferous woodlands with which reafforestation schemes are splashing the English countryside bring no bright colours, but only shades of green and brown in a background of gloom. That is what the Jurassic and all previous sceneries must have looked like, for as yet true flowering plants had not been evolved, or, if they had been, were confined to out-of-the-way uplands where conditions for preservation as fossils were far from favourable.

One outstanding feature which distinguishes flowering plants or *angiosperms* from gymnosperms is the possession of a special covering which encloses and protects the young and developing seeds. This is the seed-box (*angeios* = a vessel) or *carpel*. The angiosperms have other characteristic features. They have stamens, highly modified leafy structures, which carry compound sporangia called *anthers*, packed with pollen. Their stems and trunks contain little soft tissue and consist almost entirely of wood made up of thick-walled tubes which, when newly formed, carry water with dissolved mineral food materials, drawn from the soil, up to the leaves to be converted into food. Later these tubes help to make up the solid wood. Anticipations of most of the more or less distinctive features of flowering plants already existed during the Jurassic, but they were distributed among the various members of the flora. The steps by which they were further improved and assembled together in one type of plant are still unknown.

The nearest approach to the dream picture of the angiosperm ancestor among Jurassic plants has been found in a group of tree-ferns known as the *Bennettitales*. These differed from other tree-ferns in having their unfertilized and developing seeds clustered together upon a pear-shaped receptacle. Around this cluster were gathered a number of leaves which bore anthers. This arrangement, though it closely resembled that in a true flower, was still far from fulfilling the requirements that must be looked for in that ancestor.

It seems highly probable that somewhere in the late Jurassic landscape patches of bright colours – red, yellow, and white – had begun to appear, for well-developed flowering plants

already existed very early in Cretaceous times. They displayed their decorative effects of summer flowers and autumn leaves on the lowlands in regions which, strange to say, now lie within the Arctic circle. Deposits of that age in west Greenland have yielded fossil leaves of magnolia and persimmon, of oak and plane. This early appearance of magnolia is of peculiar interest for, among existing plants, this one seems to offer the nearest approach to the ancestor of the angiosperms. Nevertheless between it and the Bennettitales there is still a great gulf that has to be bridged.

From the Arctic these trees spread southwards into both the old and the new worlds. By the end of the Cretaceous the woodlands were clothed in gayer garments. It is pleasant to think that the birds which now also livened the air, had begun to tune their voices, and the bees to hum. In early Tertiary times there was little to distinguish the woodland scenery from that of modern times.

Up to this point attention has been given entirely to tree forms, but in the painting of the present-day scenery small flowering plants, herbs, and grasses, play a very prominent part. Indeed over extensive areas they carpet the ground to the complete exclusion of trees. Unfortunately fossil remains of these small plants are rare. No doubt this is largely due to the fact that their leaves are not caught by the wind as they fall from a height, but they fade, fall, and decay where they grow. Nevertheless fossils have been found in Cretaceous rocks in many parts of the world. That they must have been present in the glades and open spaces is indicated by the existence at the dawn of the Cenozoic of herbivorous mammals having teeth that were adapted for crushing soft food. In Middle Cenozoic, however, the teeth of many of these had been evolved and adapted for grinding dry grasses and herbage such as now grow on the treeless grasslands of the world. All this reflects a slow but widespread change of climate. In the early Cenozoic this was mild and moist even as far as the polar latitudes. But the milder belts receded slowly to the middle latitudes. At the same time mountain-building movements, especially near the Pacific sea-board, screened off the moisture-laden winds, and conse-

quently the climate became drier over large areas. The woodlands with their faunas withdrew southwards and left broad open spaces where the carpet vegetation became adapted to the recurrent seasonal droughts and rainfall. In the lower latitudes those warmth-loving woodlands still survive as tropical forests. In the higher latitudes the trees with thick bark, and leaves that could be shed as the rigours of cold winters set in, remained and reigned in the temperate woodlands. Thus was established the general pattern of the world picture as we see it now: a wonderful and beautiful complex made up of contributions from all grades of plants from the lowest to the highest, relics of the vegetation stages of all the ages.

27

THE LOWEST ANIMALS

THE earliest undoubted traces of animal life that have been found are worm borings and trails which have been brought to light in late Pre-Cambrian rocks. But worms had already attained a moderately high grade in the evolution of animal structure. Their presence may accordingly be taken as evidence that the lower grades, which now include jelly-fish, sponges, and Protozoa or single-celled animals, had been in existence already for a very long time. Hitherto no really authentic remains of the earliest of these lowly creatures have been found. This lack of fossil evidence may be ascribed to the very unsubstantial character of their bodies together with the absence of any skeleton. In view of all this, special interest is attached to a discovery made in 1910 by C.D. Walcott in the Middle Cambrian rocks of British Columbia. There he found a band of black slaty shale, about four feet thick, in which remains of these and other lowly soft-bodied creatures were found in profusion. Like the dried-up body of a jelly-fish, left stranded on a beach, these were no more than films lying on the surfaces of the shale layers. These films had been reduced to

carbon and were distinguished from the dull-looking rocky matrix by having a shiny surface. No less than 130 species of animals were distinguished – sponges, jelly-fish, worms, and even arthropods were preserved in such perfection that it was possible to make out the structure of some of their internal organs. This find is unique in the annals of geological science, for never in any rocks of later date have such perfectly preserved memorials of these lowly organisms been found. The fact that they have been found encourages the hope that other similar deposits of earlier or of later date may yet be unearthed.

What the precise conditions were that led to the preservation of those Cambrian remains it is difficult to say. The facts as they stand imply sea-water that was teeming with animal life swimming about freely near the surface, far enough from the land to be beyond the reach of all but the finest sediments, deep enough to be undisturbed by passing storms, still enough for the bottom waters to become so stagnant that they were uninhabited even by scavengers which fed on dead organisms. Uninhabited because the fumes of sulphuretted hydrogen emitted by the decomposing bodies were not carried away by currents. Here then these bodies lay and their ghostly relics were preserved.

Among the countless multitudes of single-celled animals that must have existed, two groups had begun to make shells or skeletons that could be more easily preserved in the rocks. Some of these, the Radiolaria, made use of silica extracted from the water. This they wove into a fairy network and shaped into forms of wonderful symmetry and dreamlike beauty. Examples of these have been found in rocks of many ages. Others, known as Foraminifera, were slightly larger and much more abundant and varied. A few built for themselves shells made up of sand grains picked up from the sea floor. The majority secreted shells of lime, some of which were as transparent as glass, and others opaque white, like egg shells. The simplest were straight or coiled tubes. The majority, however, were made up of a succession of chambers increasing in size and arranged in straight or curved lines or, more commonly, in closed coils or spires. It is hopeless to attempt to sum up in a

few lines the hundreds of volumes that have been written to describe them.

The small shells make up for their minuteness by their large numbers. They played a considerable part in building up massive limestones, especially during the Carboniferous and Cretaceous periods. In Tertiary times one group made shells as much as an inch or more in diameter. Some were the same size and shape as a penny and have been named *nummulites* (Lat. *nummulus* = small coin). These giant Foraminifera abound in thick limestones formed on the floor of that ancient mediterranean sea called Tethys. These nummulitic limestones range across the Old World from the Atlas mountains and the Pyrenees to the Himalayas and thence to the Isles of the Pacific. Many clays and shales also yield numerous Foraminifera. The geologist, searching for oil, finds them useful for correlating the rocks passed through when he puts down a series of borings.

At the present time Foraminifera abound in the sea. They make up, however, only a small section of the unicellular animals that exist. No other group of living things illustrates so well the versatility of living substance in its responsiveness to nature around, for these minute creatures, lowly as they are, have become extraordinarily specialized in many directions and exhibit an almost endless variety in modes of life. They swim. They float. They grovel in mud and garbage. They make their homes on and even inside the bodies of other animals, thereby causing nasty diseases and complaints such as malaria. All this implies a very long history. Moreover they must have been the first animals to invade the land. Their entry into that realm probably coincided with that of the simplest algae, and may have taken place through the medium of fresh-water muds and marshes.

Though some Protozoa are colonial in habit each individual led its own separate life. It was a great step forward in the history of living things when Nature bound them together in a new arrangement, in clusters of cells performing distinct and separate functions. Thus, for example, in the sponges some cells caught and digested food, some served the purposes of

reproduction, and others secreted silica, lime, or silk to provide a supporting framework for the whole. At first this framework consisted of a tangle of beautifully shaped spicules which fell apart when the flesh decayed and mingled with the mud on the sea floor. Such spicules have been found in rocks of many ages from the Cambrian onwards. In more advanced sponges the spicules were knitted together into a delicate basket-work of transparent shining silica, exhibiting in different sponges a great range of shapes from that of a deep narrow vase to a wide-open or even inverted wineglass. Many such were immured in the muds which ultimately became the chalk foundations of the rolling downs. Rain-water percolating through the chalk dissolved most of the spicules and became, in consequence, practically saturated with silica. When this solution came into the vicinity of the more massive basket-like skeletons it deposited the silica around them, and thus produced hard nodules of dark glassy material called flint.

While sponges have survived the passage of the ages, other early attempts made by Nature to produce multicellular animals do not appear to have been quite so lastingly successful. One such is represented by the fossil *Archaeocyathus*. The skeletons of these consisted of a limy framework resembling the basket-work of the sponge, but having the regular symmetry of a coral. They are found in the Cambrian of Australia, North America, and other parts of the world where they occur in such numbers as to justify a place for them among rock-forming animals. *Archaeocyathus* and its allies ran a short course and rapidly became extinct.

The Coelentera represent the most successful attempt to bind numerous cells together into a coordinated and larger whole. In them the cells which had a common function were placed together in layers or groups called *tissues*. The body is symmetrical in shape and consists of two primary layers covering the outside and lining the inside of the body respectively. The remarkable fossil assemblage discovered by Walcott in the Cambrian of British Columbia provides the earliest evidence of their existence. During the Ordovician some of them began to secrete lime in those familiar forms known as corals. From that

time onwards similar remains are common and are at times very abundant. It may be assumed that, as at the present day, so throughout the ages, many of their relatives died and left behind them no such evidences of their existence.

The simplest form living to-day is called *Hydra* and lives in fresh-water ponds. Its body is cylindrical. Around the mouth, which is at one end, are eight tentacles with which it captures Protozoa and other minute organisms for food. The sea anemone and jelly-fish are larger and more highly organized. They illustrate the two commonest types of bodily form found among Coelentera. That of the former, which closely resembles *Hydra*, is described as hydroid; that of the latter, medusoid. Impressions made by Medusae are known in the rocks, but they are rare. On the other hand calcareous structures made by hydroids abound in the form of corals.

Many Coelentera exhibit both types of bodily form during the individual lifetime. These are classed as Hydromedusae. They usually live in colonies in which all the individuals are attached to a common stem, like the flowers of a foxglove. This stem is a hollow fleshy tube uniting the digestive cavities of all the hydroid polyps with one another. Usually the whole colony is enclosed in a thin horny covering which may be preserved in the fossil state. A few, like the red coral, have a limy covering instead. At the present time this type plays only an insignificant part in the populations of the sea, but in Devonian times some of them, such as *Stromatopora*, built up large hemispherical masses of coral and produced a limestone which when polished can be used for decorative purposes.

The sea anemone, as its name implies, is like a flower. Its beauty of form and colour makes the rock pools, where it often lives, almost as attractive to holiday makers as a formal garden. This feature won for this numerous and varied group the appropriate name of *Anthozoa* (*anthos*=flower, *zoon*=animal). The Anthozoa played a prominent part in the scenery of the sea floor. Though solitary individuals occurred, colonial groups were much more common and striking. In the former each individual began life by secreting lime around its base in the form of a minute cup. As it grew it deposited lime upon the

rim, ring upon ring, until a tall tube was formed. All the tubes of a colony stood side by side like the pipes of an organ. These 'organ pipe' corals were the chief reef builders in the Silurian and Devonian seas. Of the many beautiful fossils found, two must be mentioned. First there is the chain coral, *Catenularia*, in which the pipes are arranged in single file. As seen from above their openings were in series and looked like the links of

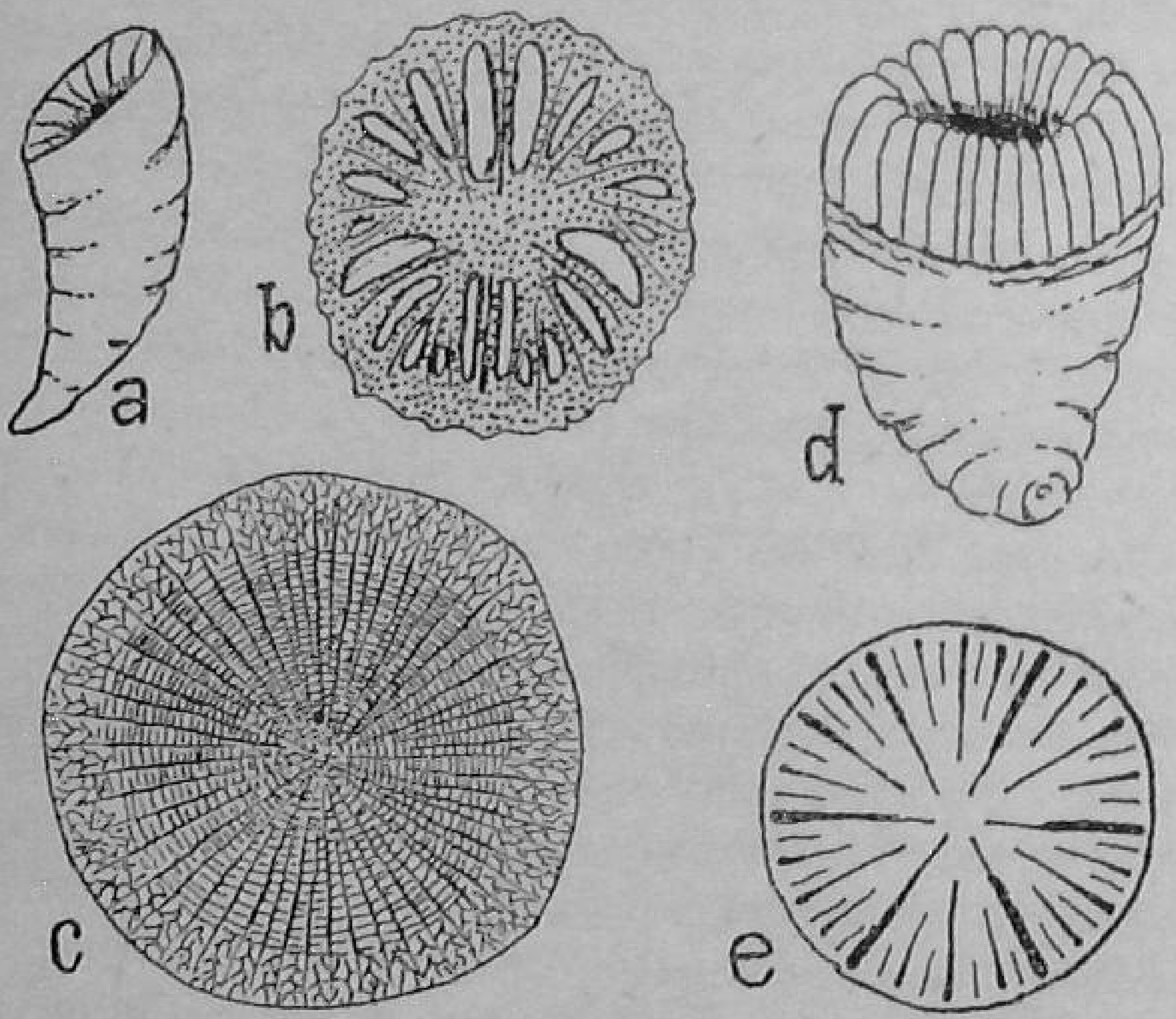


FIG. 13. TYPES OF FOSSIL CORALS

From Palaeozoic rocks: *Zaphrentis* (a) complete, (b) a cross section, (c) a section of *Cyathophyllum*

From Mesozoic rocks: *Montlivaltia* (d) complete, (e) section.

a chain. In another coral the tubes were closely packed against one another like the cells in a honey-comb. Its name is *Favosites*, but it is popularly known as honey-comb coral.

Living in the same reefs was another type of anthozoan with much larger polyps each of which built up a cone-shaped corallite. This normally had a maximum diameter of about ½ inch, but in some this exceeded 2 or even 3 inches. Unlike the other Anthozoa, just considered, the cavity of the cone in these

was divided by vertical partitions or *septa* projecting inwards from the walls and attached to one another along their inner margins. As seen in slices across the coral these were arranged with a two-sided symmetry. This plan of structure is typically exhibited by *Zaphrentis*. Simple corals having this zaphrentid type of structure appeared during the Ordovician and continued with comparatively little change until Lower Carboniferous times. This series of corals, which was so stable for nearly 200 million years, was a radicle stock. That is to say it was the root that gave rise at intervals to other and much shorter-lived stocks, each of which evolved rapidly and underwent many changes which culminated in massive reef-building colonies. Practically the same series of changes was repeated during the Silurian, the Devonian, and again during the Carboniferous. The resemblance between the members of these successive stocks was so striking that early workers were deceived as to their true relationships. Thus, for example, at one stage in the evolution of each stock single corals were produced which had a great number of closely packed septa radially arranged with only the slightest trace of two-sided symmetry. To these they gave the name *Cyathophyllum*, for they thought that the Carboniferous and Devonian individuals had descended from the Silurian ones having the same structure. Careful work, however, has shown that this is not the case; that in all three '*Cyathophyllum*' had been independently evolved at three different times. The evolving of this cyathophylloid type of structure in these three independent stocks or series of corals illustrates the Principle of Parallel Evolution, a principle which is frequently evinced among fossils. It will be useful if we now describe briefly an example of such careful work.

In the gorge through which the River Avon flows, near the city of Bristol, Carboniferous limestone having a thickness of 4000 feet is exposed. This rock was laid down in seas that covered much of Western Europe in which existed conditions very favourable to the growth of corals. The seas remained for about 50 million years, a time long enough for corals and other animals to undergo a considerable evolutionary change which

was recorded in the fossils now found in the rock. Dr Vaughan, the mathematics master in a well-known local school, made a prolonged study of the rocks in the gorge, and of the fossils they contained; more especially the corals and brachiopods. He kept careful records of the precise levels from which he collected his specimens and was therefore able to trace the progressive differences shown by the fossils from successive layers. Having become familiar with the characteristics of the fossils in each layer he, and many co-workers who had acquired his knowledge, applied the same methods to limestones of the same age in other parts of the country. In addition to working out the story of the evolution of the corals they were enabled to reconstruct the evolution of the geography of this part of the world during early Carboniferous times. Recognizing each set of rocks by the assemblage of fossils it contained, they followed it into South Wales and the adjoining counties. In this way they found that the northern limits of the sets or zones, taken in order from below upwards, shifted northwards. As these limits marked the positions of the coastlines at the corresponding periods of time they were able to piece together a series of pictures of the sea spreading northwards over the lowlands of the Old Red Sandstone landscape. They followed it as it crept round uplands which occupied the Midlands and converted them into an island known as St George's Land, Protobritain. Thence the sea spread across the north of England and invaded the Midland Valley of Scotland.

Returning now to the story of corals, during the Permian, for some unknown reason, the large corals which had played such a prominent part in the clear waters of the Palaeozoic seas declined and disappeared. Meanwhile another group of moderately large Anthozoa began, for the first time in their history, to secrete lime, to make corals, and to occupy the vacancy thus left in nature. They also started this new phase in their history by building single or simple corals. In this case, however, the earliest ones had only six partitions or septa and these were radially arranged. As the evolution of the group proceeded, the number of septa increased by the insertion of six new septa in the spaces between the first six. Later a third set of twelve was

inserted. In Jurassic times the solitary corals evolved rapidly and became completely overshadowed by a rich variety of branching, compact, and solid colonies. These were dominant in the reefs of the Jurassic seas of Britain, Western Europe, and elsewhere. This fact shows that in the middle latitudes the seas and the climate were warmer then than they are now.

In these compound corals the surrounding walls of each corallite were solid and sometimes the spaces between the branches were similarly filled. But during the Cretaceous a new type of modification appeared in which the lime was more economically and advantageously used. The walls of the corallites were pierced by numerous holes and became like a network. The infilling between the branches was also very porous like a sponge. This type advanced rapidly during the Tertiary and is dominant in present-day reefs in which the colonies are very varied and beautiful. It has been estimated that some of the larger colonies have taken as long as 200 years to grow to their present size.

In Ordovician and Silurian rock fossils called graptolites often abound especially in dark or black shales. They are by no means conspicuous objects and often look like mere lead-pencil marks on the surface of the shale. It is this which suggested the name 'grapholite' now modified to 'graptolite'. Despite their insignificance they have been supremely valuable to geologists as means of correlating rocks at places widely separate on the surface of the earth. They owe their usefulness in this respect to the fact that the animals which made them lived in delicate colonies that dangled from special floating devices near the surface of the water. They were, therefore, at the mercy of sea currents and became in consequence widely distributed across the oceans.

For a long time graptolites have been classed with the hydromedusae, for their fossilized supporting frame-work closely resembles the horn-like covering of some Hydromedusae, popularly known by beach naturalists as sea mosses, especially those which have delicate toothed margins looking like the edge of a saw. Each tooth represents a minute cup in which a little polyp lived. But students of fossils have never quite been

satisfied that this assignment to the Coelentera was the correct one. In recent years new light has come from another quarter. Among the treasures dredged up from the floor of the ocean by the scientists on board the research ship *Challenger* was a curious creature to which the name *Cephalodiscus* was given. Careful dissection showed that this strange animal had points of similarity to very primitive forerunners of the vertebrates which were called Protochordates. It was a branching colonial animal with a horny covering. Recent investigations made into

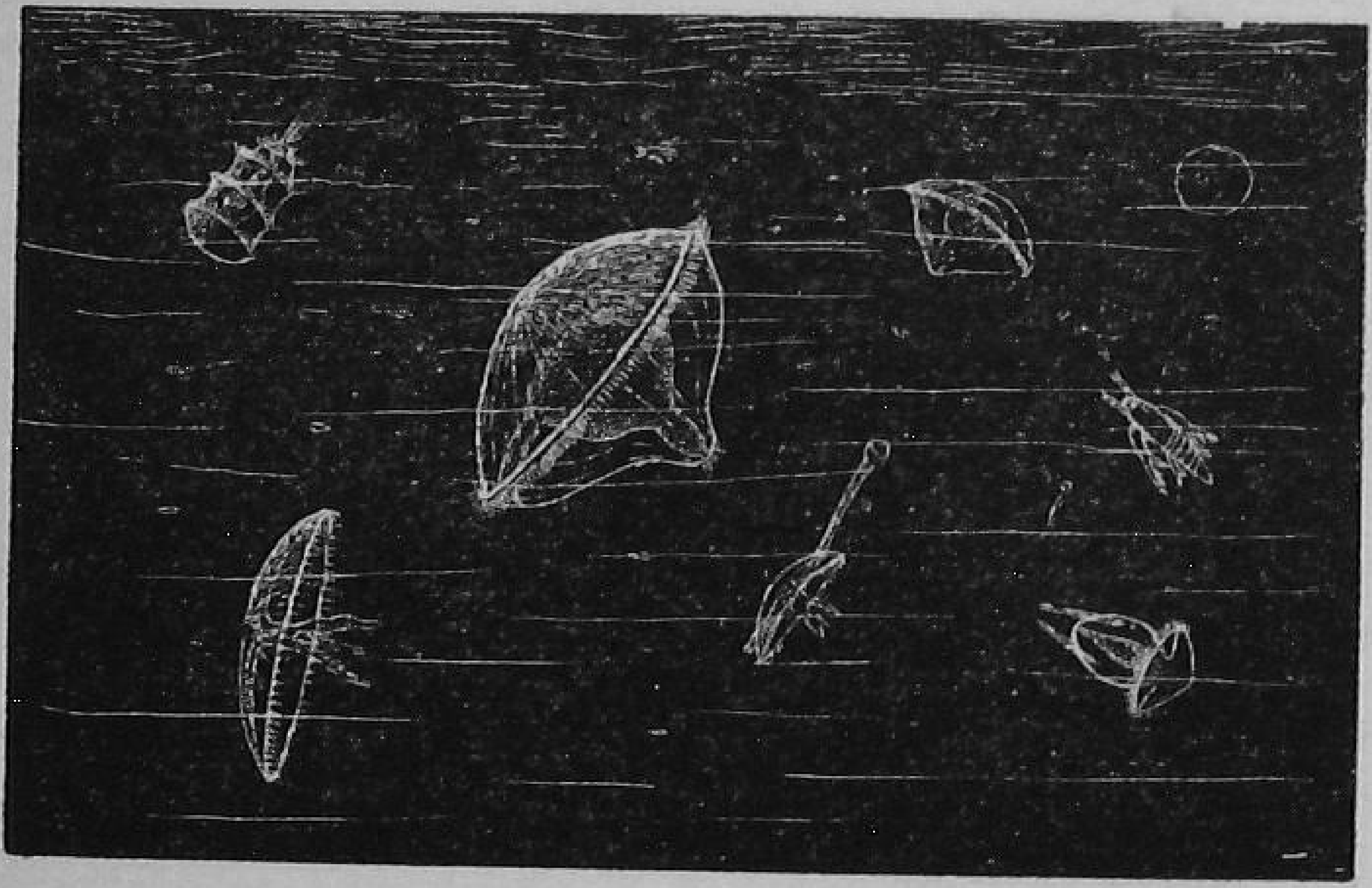


FIG. 14. FLEETING GLIMPSES OF AN EARLY PRE-CAMBRIAN FAUNA

A medusa and larvae of a marine worm, a brachiopod, a stone lily, an arthropod

the structure of the colony and its covering revealed a striking similarity between this and the structure of the graptolites. It would seem then that instead of belonging to the very low grade of animal life represented by the Coelentera the graptolites must be promoted to a position among the far-off forerunners of the vertebrates.

The last occupants in this caravan of lowly animals to be considered are the worms. With such soft-bodied creatures

fossil remains are scanty and rare. Nevertheless they are of outstanding theoretical interest for they represent the ancestral stock from which most, if not all, the other creatures evolved.

Many marine worms, when they hatch out from the egg, issue forth as larvae which are not at all worm-like. On the contrary they resemble little jelly-fishes, but they have a much more complicated internal structure. Some are spherical; others are shaped like a pear with the stalk hanging down. Mollusca and other types of invertebrates have closely similar larvae. Applying the principle of recapitulation in development it would appear that these larvae represent a very early stage in the evolution of the animal kingdom which was passed through soon after the beginning of Pre-Cambrian times. The surface of the sea must then have swarmed with creatures similar to those larvae. Among living creatures the rotifers, the joy of amateur microscopists, present the nearest approach to a replica of those primeval ancestors.

After the larva has been swimming about freely for some time its lower stalk-like end begins to elongate by the growth of a succession of ring-like segments. In fact it turns into a genuine worm which, like a falling angel, drops to the floor of the sea and henceforth grovels in the mud and sand.

The unsegmented worms are quite unknown in the fossil state, but the segmented worms are represented among the fossils that were found in the Middle Cambrian shales of British Columbia. Some of the more predaceous worms in modern seas are provided with sharp hook-shaped horny jaws. These are often found as fossils at many different horizons in the rock succession, and are evidence that similarly active carnivorous worms have always existed.

Many marine worms make burrows in the floor of the sea. When they vacate their burrows, the mud flows in and both burrow and infilling may be converted into rock. A striking example of this is that of the Pipe rock, in the lowermost beds of the Cambrian of Scotland, which is riddled with fossilized worm borings. As these are sometimes more than an inch in diameter the worms must have been of giant proportions. The sea floor would have furnished a very rich feeding-ground for

fishes, had such existed, but some millions of years were to elapse before they appeared upon the scene.

An ordinary earthworm is able to climb up and down its burrow and along the surface of the ground because each segment of its body is armed with short stiff bristles by which it gets a 'grip'. In marine worms these bristles are carried on fleshy lobes projecting from the side of the body, and look like crude clumsy legs. Tracks made by such worms on the sea floor are frequently preserved, and some of them show the marks of these fleshy lobes. The fossils found in the black Cambrian shales already mentioned show that even then worms were armed with similar bristles.

Worms live also on the muddy floors of estuaries and fresh-water pools and lakes. There is little doubt that it was by a similar path that some worms eventually found their way into the soil of the land around, and became the second group of animals that gained access to dry land and survived. They were better able to do this because enough lowly vegetation must have gained a foothold on the land to provide that humus in the soil upon which earthworms feed.

28

STARFISH AND STONE LILIES

An important feature about starfishes and allied animals is that their bodies are radially symmetrical. That is to say there are a number of directions along which the body could be cut into two in such a way that one half is the mirror image of the other. And yet, strange to relate, when their eggs hatch out the little creatures that emerge have a two-sided symmetry and swim about freely in the water. This may be interpreted as indicating that their ancestors, which lived in early Pre-Cambrian times, were also bilaterally symmetrical and did not crawl on the sea floor but were also free-swimmers.

After a while the larva settles down upon some solid object on the sea floor and becomes attached by its front end. Its body

becomes round or slightly pear-shaped. Its internal organs twist round in such a way that the mouth is shifted to the topmost point and the vent to a spot lower down on the side of the body. By this arrangement the waste products of the bodily functions fall away without passing the mouth.

One early and very interesting fossil echinoderm, from the Ordovician rocks, is called *Aristocystis*. In a number of respects it resembled the fixed larva just described. It was pear-shaped and attached by a short stalk. Instead of being upright it lay along the ground with its mouth situated at the opposite end to the stalk. Unlike the larva its body was supported and protected by a mosaic of limy plates just under the skin. These plates were angular in shape and were irregularly arranged. Its close relatives in the early Palaeozoic seas exhibited a varied range of shapes as though Nature were experimenting to find out the best form and mode of life to suit the conditions. Unlike *Aristocystis* most of them were upright. Some were almost spherical and had three long processes stretching out from around the mouth into the surrounding water. Upon the upper side of each of these a groove ran which was equipped with a device for sending a current of water to the mouth. This caught Protozoa and other equally small plants and animals and swept them along for use as food. Normally there were five food grooves which ran down from the mouth over the sides of the body. In many the body became tall and its lower portion changed into a stalk which lifted the part with the mouth, food grooves, and internal organs well above the mud into cleaner water. This group of echinoderms attained its climax and disappeared during the Carboniferous period. From them descended the stone lilies or crinoids (*krinos*=lily) which were much more highly successful. Perhaps the most important factor in their success lay in the perfecting of the food-collecting apparatus. The food grooves, supported by limy plates, were carried on arms which stretched out into the surrounding water. At first each arm was simple and unbranched. When these were spread out horizontally there were wide spaces between in which the water was beyond the influence of the food currents. The arms, however, became

branched, at first quite simply, but later with increasing complexity. At the same time the branches increased in length. In this way all the water between the arms was effectively exploited for food. The stalk was made up of a series of stony rings placed one upon another. Separated rings are often found as fossils and are collected by children who call them 'fairy beads'.

At the present time stone lilies grow attached to the sea floor in clear sunlit waters of warm temperate and tropical seas where they congregate in great numbers like miniature forests of palm-trees. Their abundance in middle and late Palaeozoic limestones in the temperate and higher latitudes points to a wider distribution of warm climates then than now. They flourished greatly in the Carboniferous seas, and the large size of the 'fairy beads' indicates that some of their stalks must have been at least 10 feet high. These heights were attained because new rings grew and were added to the top of the stalk throughout life. When an individual died this stony framework broke and fell to pieces on the sea floor. A young stone lily grew in its place, and so the forest continued and its débris accumulated to considerable depths. The stone lilies were, therefore, important rock builders and produced masses of crinoidal limestone which, in the nineteenth century, was extensively quarried, cut into slabs, polished, and used as ornamental stones. Large quantities were exported from the Derbyshire quarries under the name of Derbyshire marble.

The crinoids rose to their climax in Carboniferous times and then declined so rapidly that they reached the verge of extinction during the Permian and Trias. The cause seems to have been almost universal, but what it was is still an unsolved mystery. Fortunately, somewhere in the world, places of refuge existed and remnants survived. With these as a fresh starting point the race entered on a new lease of life. During the Jurassic period the stone lilies regained some degree of importance and have retained it until the present day. Nevertheless the golden age was over and never returned.

In accordance with the principle of parallel evolution crinoids now evolved along some of the same lines as their

Palaeozoic predecessors. Sometimes, however, they struck out on new lines, or developed to the full tendencies only faintly manifested before. For example, if the conditions where they lived became unsuitable the animals broke off from their stalks and swam away in search of another home, moving their arms with a motion similar to that of the bell of a swimming jelly-fish. Having found a healthier spot they settled down and grew new stalks. It is not surprising to find that quite a number of crinoids adopted a free-swimming mode of life entirely. *Marsupites* and *Uintacrinus* were striking examples that lived in the Cretaceous seas. *Antedon* is another that lives now in the sea around Britain.

The sea urchins, unlike the stone lilies, have compact bodies. Their general history has been like that of the crinoids, but in reverse. They remained obscure during the Palaeozoic, but rose to prominence in Mesozoic and later times. They appeared first in the Ordovician and advanced to a minor climax in the Carboniferous. In form they varied from being spherical to being flattened and bun-shaped. Their armour was flexible and made up of numerous plates. Some of these were pierced with pores for the passage of tube feet, and were regularly arranged along five longitudinal zones extending from the centre of the upper surface to that of the lower, where the mouth was situated.

At the close of the Carboniferous they too became almost extinct. A few refugees survived and gave origin to fresh stocks that evolved with increasing variety and numbers to their climax at the present time. In these later races the plates were regularly arranged in twenty vertical rows, extending from the apex to the mouth. Two rows of plates with pores alternated with two in which these were absent. The basal shape of the body was a slightly flattened sphere as in *Cidaris*. More usually it was hemispherical with the under surface much more flattened. In *Cidaris* as in many others the outer surface of the non-perforated plates was covered with knob-like tubercules, on each of which was a spine articulated by a ball-and-socket joint. In most sea urchins these spines were sharp and stuck out all over the body like the prickles of a rolled-up hedgehog.

No doubt they created difficulties for would-be enemies. In some as in *Cidaris* these 'spines' were stout and club-shaped, and it is difficult to see what function, if any, they served. It may be that they were no more than mere dumps for the excess of lime excreted from the living tissues.

During Jurassic times some of the sea urchins started off on a fresh evolutionary path. They abandoned their radial symmetry, with the freedom it gave for easy movement in any direction, and adopted the two-sided symmetry associated with movement in one direction only. At the same time the spines became fine and formed a covering that looked like fur. These changes attained a full development during the Cretaceous in the heart urchins in which the body had become heart-shaped. The mouth moved forward from its central position on the under side and its hinder margin bent down into the form of a scoop, a convenient arrangement for a creature which had now become a mud feeder.

One of the heart urchins, *Micraster* by name, was made the special subject for study by Dr Rowe, an investigator who lived in the early part of this century. He lived in the south of England and, like Vaughan at Bristol, collected his specimens carefully layer by layer from the chalk which is 1000 feet thick and remarkably uniform in character throughout the greater part of its thickness. He carefully recorded the precise position of specimens as he found them in the faces of cliffs and quarries. By a very painstaking examination of his material he discovered the series of evolutionary changes passed through in the shape of the mouth, the outline of the body, the decoration on the pore-bearing plates, and so on. He found that these changes held good for *Micraster* found everywhere. He then divided this thick mass of chalk into zones each characterized by *Micraster* at like stages in their evolution. He thus put into the hands of geologists a valuable instrument for solving sundry theoretical problems such as the geography of the Cretaceous seas and also practical problems such as the precise level reached by a boring tool in its passage down through this uniform rock. He also made a most valuable contribution to the study of Evolution. Dr Rowe was a good example of what may be

done for the science of Geology by a non-professional geologist.

Starfishes are perhaps much more familiar to the laity than sea urchins. They live in shallow water. Sometimes they creep up the beach with the incoming tide and are left stranded when it retires. They have had a long and uneventful history, for their remains are found in rocks of all ages from the Ordovician onwards. Like so many other organisms they suffered a setback at the close of the Palaeozoic and the opening of the Mesozoic eras. The earliest starfishes resembled sea urchins, from which they descended, in the possession of an armour of closely fitting plates. In later and modern forms these plates are reduced to mere rods which are linked together in a network.

29

SNAILS AND EVOLUTION

One of the treasures in the University of Nottingham is a cabinet of inlaid wood fitted with little drawers that belonged to Florence Nightingale. In it is a collection of sea shells that she made and arranged. This throws an interesting side light on the mind and character of that great woman. Similar but larger collections may be seen in every museum. Consequently, the amazing range in beauty of form in shells produced by the relatives of despised slugs and snails is made familiar to many folk.

Crabs and lobsters are often called shell-fish, but their shells are as different from these molluscan shells as a suit of armour is from a cottage. The shell of a crab is the much-hardened skin of the animal and is essentially part of its body. A molluscan shell is a dwelling, secreted by the skin, to which the occupant is tethered by a cord of flesh lest it should go astray and become a poor homeless vagrant like the slug.

These shells are made of lime, and it is natural that generally those of the sea molluscs are much stouter and stronger than those of the fresh-water and land forms.

The individual among the more lowly molluscs starts life as a free-swimming larva which in some respects is strikingly like that of some marine worms. This fact has an interesting bearing on the ancestry of the Mollusca and takes us back in imagination to those days in Pre-Cambrian times when, among the jelly-fishes that swarmed in the waters, there were creatures not unlike them in habit and appearance, feeding also on the same minute Protozoa and single-celled algae which were diffusely scattered around them. There is of course no direct evidence for this in the rocks themselves. This story is only what sober-minded people call an extrapolation of the facts, in other words a flight of imagination based on facts. In due time, for reasons as yet not understood, the descendants of these fairy-like creatures settled on the bottom of the sea. They came to earth and we must do likewise.

The earliest fossil remains of this great group of invertebrates come from the Cambrian rocks. They occur in the form of low conical shells, similar to those of the limpet, and of corkscrew spirals, like that of the ordinary snail only taller. Some idea of the appearance of these creatures in life may be gained by piecing together the essential features common to all the living forms. They must have crawled about on the flat under-surface of the body which is called the foot. It is in reference to this feature that this group of Mollusca is called the *Gastropoda* (*gaster*=belly, *podos*=foot). The main internal organs of the body were contained in a large hump rising from the top surface of the body. It was conical in shape and covered by the shell. The mouth and sensitive processes were carried at the anterior end of the body. In the front surface of the hump was a pocket, the mantle cavity, in which the paired gills were situated, and which opened just behind the head. A continual stream of water flowed in at the corners of the pocket and bathed the gills. It then escaped at the middle of the opening and carried away the waste products of the body which had been discharged into the cavity.

The shell was built up on the surface of the hump by the secretion of delicate films of lime which were added to the inside of the shell. As the animal grew each film now extended

a little beyond the previous one and thus the shell increased in size. This increase took place more rapidly in front, over the margin of the mantle cavity, than behind, with the result that the shell became coiled in one plane like a watch-spring. A well-known fossil with the euphonious name *Bellerophon* had a shell of this type. The front margin, over the mouth of the shell, had a long notch in the middle, through which the polluted water escaped from the mantle cavity without encountering the inflowing stream. There are reasons for believing that this sea snail could swim about freely in the water.

Shells having the corkscrew spiral exhibited a much greater range of shapes from being almost flat to being tall and turreted. Fossils showing various grades of these shapes are found in the Silurian rocks. One low-spired type, *Pleurotomaria*, first appeared in the Silurian seas and continued on through the Mesozoic to Tertiary times. It was long believed to be extinct, but at the end of the nineteenth century live specimens were dredged up from the floor of the Australian seas. These provided material for studying the anatomy of a very primitive and characteristic Palaeozoic gastropod. Such finds are often referred to by the self-contradictory name of 'living fossils', and the finding of them marks a highlight in the life of a naturalist.

A gastropod shell consists fundamentally of a tall cone that has been coiled into a spiral. In cross-section this cone is primarily circular, a shape which is usual in ancient and primitive types. As the coil tightens, however, one side of the cone, together with the hump which secretes it, becomes flattened at the surface of contact along the axis of the spire. The mouth of the shell is correspondingly changed from being circular to being approximately half-moon shaped. In association with this the gill, situated on that side of the mantle cavity, degenerated and ultimately disappeared. One other outcome was that the water flowed into the mantle cavity at the front corner over the gill and out at the back. This fundamental change in the gastropod economy had already taken place in a few sea snails during the Palaeozoic. But the numbers increased throughout later times. To-day that type makes up the majority of the gastropod population in the seas.

The shape of the whole shell varies in accordance with that of the fundamental cone. If this has a wide base the shell is short and stout. If the base is narrow the shell is tall and slim. To this wide variability of form is added great variability in the surface ornamentation. In the earliest Palaeozoic shells the surface was smooth and marked only by growth lines which is still the case in most land and fresh-water forms. In late Palaeozoic times the shells are sometimes marked with slightly projecting ridges or ribs. In some the ribs traverse the spiral lengthwise. In others they are at right angles to this. In Mesozoic times both types of rib were often present in the same shell, and consequently the surface became ornamented with a delicate network pattern. It is not surprising that at the crossing points of the ribs there was a tendency for them to thicken and develop into knobs or even spines. Ornamentation became increasingly developed in Tertiary times and is at its maximum to-day.

Unlike the corals and echinoderms the gastropods suffered no setback in their history. They have progressed steadily through all the eras up to their climax in the present. Though the vast majority of gastropods are marine, it is a testimony to the adaptability of their constitution that in Cretaceous times one of their branches invaded both fresh-water and dry land. In these the mantle cavity became adapted to function as a lung for breathing air. To-day they are ubiquitous, and any gardener will agree, somewhat grudgingly, that they are successful as land animals.

An interesting feature about the gastropod story is that, while new types were appearing, ancient and primitive types also survived and played their part in the marvellous and beautiful pageant of animal life. In this way the gastropods illustrate a general principle which seems to pervade the whole process of creation. It is that increasing complexity and beauty in nature is brought about by a harmonious blending of old and new. First the blade, then the ear, and then the full corn doth appear; all these together make up the perfect whole.

Unlike crabs and lobsters, snails do not cast their shells aside at intervals, but retain the same shell throughout life. Conse-

quently each animal preserves in its shell a record of every stage in its growth. This makes it possible to work out the detailed story of the individual's development by a close inspection of the shell itself. For example, in a well-preserved whelk shell the extreme tip has a smooth surface. This part of it was made by the little creature while it was still in the egg. In the next coil or two spiral ribs appear. Lower down these are crossed by transverse ribs, and eventually slight swellings are seen at the crossing points of the ribs. It will be noticed at once that there is a close parallel between the general development of ornamentation during the growth of this individual and the general evolution of ornamentation in gastropods through the ages. This is another illustration of the principle of Recapitulation which strikes the eye of the student of fossils so frequently that he is forced to conclude that the principle is not an imaginary one, but has reality as a method of working in the process of creation. In making an individual, Nature does in fact follow the same general procedure as in evolving a race. A lifetime, however, is only an infinitesimal part of an era. It is not surprising, therefore, that in making individuals she carries out the procedure only in outline, missing out details here, taking short cuts there and sometimes doing the same thing in another way. All this makes the study of Nature's methods vastly more fascinating.

If trouble be taken to examine only half a dozen whelk shells it will be found that no two are exactly alike. Some are almost smooth throughout life. Others are ornamented only with fine spiral ribs for a quarter, a half, or rarely the whole shell. In others again they are clustered together into swollen ridges. The transverse decorations show similar changes. There is in fact endless variation in the shells even of one species or type. All this variety is produced by different arrangements and different emphasis of a few simple features or characters. Nature is like the musician who produces many different tunes and airs from only a few notes; or like the author who writes many words, sentences, and even books with but a few letters.

Students of heredity have in recent years devoted much time and skill to experimenting with such simple characters as the

colours of flowers, the resistance or non-resistance of wheat to disease. They have taken two carefully chosen individuals showing respectively the two characters they wish to study. From these they have bred a number of generations of individuals under carefully controlled conditions. In this way they have discovered many illuminating facts about the ways in which Nature sorts out and rearranges characters as they are passed on from generation to generation. Having discovered Nature's way they have followed her example with great benefit to mankind, in the beautification of gardens, the improvement of wheat stock, and, of course, in numerous other ways. This branch of science is called Genetics.

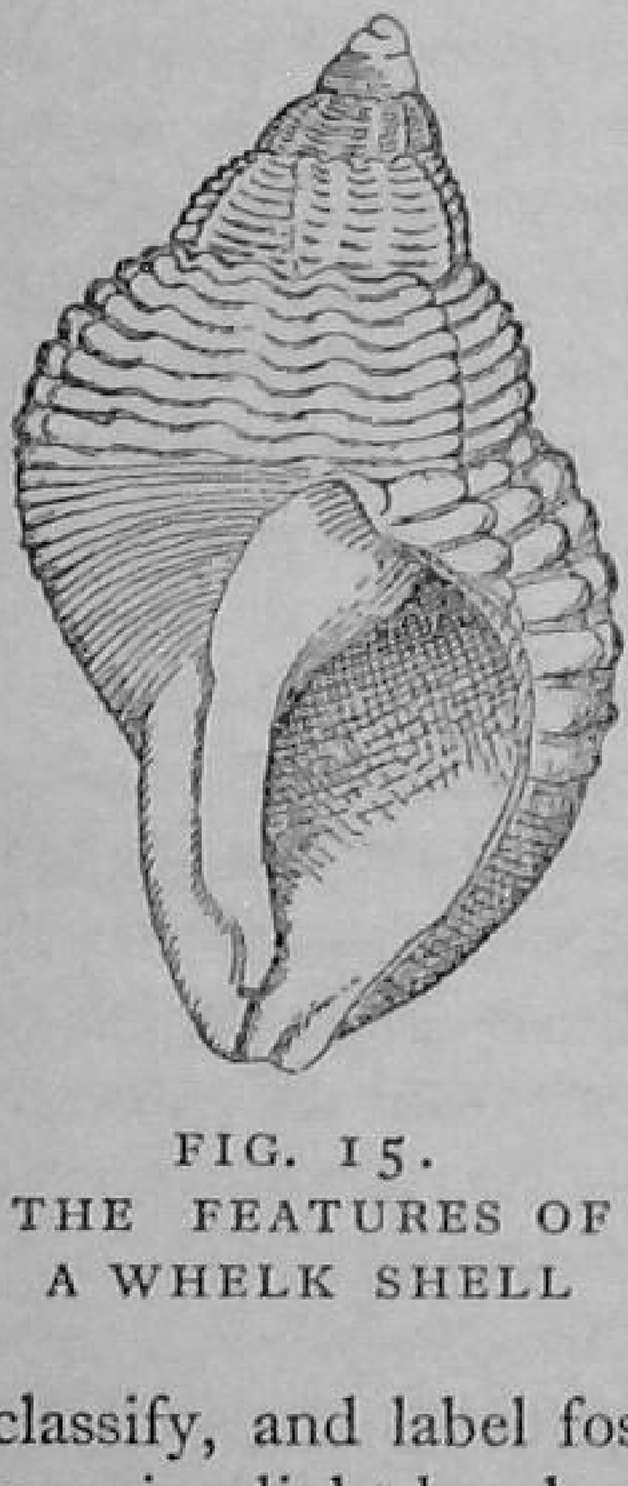


FIG. 15.
THE FEATURES OF A WHELK SHELL

In addition to arriving at a fuller understanding of the underlying processes of heredity, geneticists have gained a further insight into the working of Nature's evolutionary activities at the present time. That insight must, however, be incomplete, and at times even mislead, unless it takes careful account also of the records of Nature's own experiments in bygone ages as preserved in the rocks. For this purpose it is not sufficient to collect, classify, and label fossils. It is true that by doing only this amazing light has been thrown upon the story of life on the earth in past ages. Nevertheless, if the fundamental aspects of the story of evolution that have been already glimpsed by geneticists are to be still more fully elucidated, some students of fossils must feel called to make copious collections of the remains of more or less common and abundant types, and to collect them from a close succession of carefully recorded levels. Having done this they must, like the geneticists, spend laborious days, it may be years, in following the behaviour of individual characters through the development of individuals and through the ever-changing varieties that appear

in successive generations. Work of this kind has already been done and a science of Palaeogenetics has been started on its way. So then even slugs and snails may be sources of inspiration.

It will be convenient at this stage to make an excursion into another group of Mollusca, which includes cockles, mussels, and oysters, whose soft bodies are enclosed in a pair of shells or valves and which were for a long time known as bivalves.

When an oyster hatches out of the egg it goes out into life as a free-swimming larva resembling those of many marine worms. What has been said about the latter and the way in which they reflect the probable make-up of the fauna in the early Pre-Cambrian sea may be said of these also.

Like the gastropods these bivalves played only an insignificant part in the life of the Palaeozoic seas. They too had no marked setback at the close of the Palaeozoic era, but progressed steadily with increasing numbers and varieties up to the present.

Like the gastropods, their natural haunts are on the sea floor. A few primitive kinds crept about on a flat foot, but in the rest the so-called foot was compressed from side to side into a hatchet-shaped organ. This gave rise to the name *Pelecypoda* (*pelekus*=axe) for this branch of the Mollusca. With this 'foot' pushed into the mud or sand the animal is able to plough its way slowly from place to place. The valves lying on either side of the body meet in a sharp edge and do not offer any resistance to the movement.

Several modes of life are open to these bivalves. In the normal mode just indicated the shell is oval in outline and compressed from side to side. In some cases the foot is used for pulling the animal down into the sand or mud, and pushing it out again. The adoption of this burrowing habit is accompanied by an elongation of the shell which thus offers the minimum of resistance. This is seen to perfection in the razor-shell. Others again bore their way into hard rock by using the front of the shell, which is roughened, as a drill. It seems strange that a flimsy shell should be capable of drilling its way into a hard rock. This only illustrates the advantage a live creature has over a dead stone, for the shell as it is worn can be constantly

renewed. No bivalve, however, makes more than one boring. It starts its task when it is young and very small. The deeper it bores the older it is and the bigger it becomes, but the entrance remains small. The creature has in fact made itself a prisoner for life. Boring shells also are elongated. Since, however, the operation of boring involves a rotary movement the two valves together tend to be cylindrical.

Many bivalves live anchored for life to one spot, as, for example, the mussel. A small gland on the foot secretes a number of silken threads with their free ends stuck to the surface of the rock. Mussels are abundant on rocky surfaces between the tide lines, where the incoming water brings them food and oxygen. The lower part of the shell, where it is in contact with the rock, is flattened, but the upper, with its sharp edge, is well suited for resisting the smashing blows of the breakers, but is exceedingly uncomfortable for paddlers who must walk over them. The Oyster is another bivalve that is fixed for life. At the end of its youthful free-swimming career it lies down on one side on the surface of a stone or another shell. As the loose skin, or mantle, on that side of the body secretes its shell, at the same time it cements this to the rock.

Some of the early collectors of pelecypod shells classified them on the basis of the characteristics just described that were associated with these differing modes of life. Advancing knowledge, however, has shown that these adaptive modifications were like red herrings drawn across the path of the student who was trying to track the evolutionary history of these interesting Mollusca. It was shown that during geological time quite unrelated types adopted similar modes of life and assumed similar shapes. After all the shell in these cases is merely a shelter or dugout of the simplest type which reflects very dimly the internal structure of the evolving animal itself.

The two valves are hinged on to one another along their upper margins. Here the shell is thick. In the earliest and most primitive bivalves the opposing surfaces of these thickened margins carried numerous small projections or teeth. As time went on the middle teeth of each series became larger and better shaped for fitting in between one another like the

business parts of a hinge. At the same time the outer teeth at the two ends of the series declined and passed away. Thus the hinge became gradually perfected. These simple shells thus provide an excellent illustration of an important evolutionary principle; according to this what is called progress follows the lines of a reduction in numbers of parts and increasing specialization of the few that remain. A little reflection will suffice to show that the same principle plays a part in human affairs as for example in education from the School Certificate to the honours degree. The boring bivalve suggests a warning.

The pelecypods first became a noticeable element in the fauna of the sea in Ordovician times. From these arose a moderately wide range of forms during the Silurian and later Palaeozoic. Like the gastropods they then suffered no appreciable setback, but continued to flourish increasingly until the present age. At each stage in this age-long progression the same old habitats and modes of life were invaded and occupied by newcomers; the same adaptive modifications were repeated. Consequently the pelecypods provide many illustrations of parallel evolution. For example, on the beaches at holiday resorts around the North Sea the shells of the boring bivalve *Pholas* are common and have long been known. In recent years a close inspection of a handful of these shells will show that among them is a quite different shell with the very appropriate name of *Petricola* (rock borer). *Pholas* has no hinge teeth, *Petricola* is well provided with these. Early in this century *Petricola* is said to have been accidentally introduced into the Thames estuary and in the course of the next quarter of a century spread all round the North Sea. This is an interesting example of the speed with which a stationary animal may become widely distributed. Needless to say the actual journeys are taken before each individual settles down to its life's work.

Though the majority of pelecypod shells are small enough to be held in the hand they do sometimes attain giant proportions. Thus, for example, in *Tridacna*, which lives in tropical seas, one valve of this prettily folded shell is big enough to serve as a baby's bath or, if artists can be quoted as testimony, a bathing-pool for nymphs.

The genus *Hippurites* and its relatives flourished in the warm waters of Tethys during Cretaceous times. Like the oyster they were cemented to a rocky surface on the sea floor by one valve. In this case, however, the animal secreted layer after layer of lime, depositing it on the inner surface of the fixed valve thus building it up into a column which, in some extreme cases, is 3 feet high. The other valve acted as a lid for the living space at the top of the column. These shells accordingly bore some similarity to very stout corals and, like them, they formed for a brief period an important element in the building up of reefs.

30

SHIPS OF PEARL

'THIS is the ship of Pearl.' With these words the Autocrat at the Breakfast Table introduces us to the pearly nautilus whose lovely shell is found cast up on many beaches in the Pacific Ocean. At first sight there appears to be nothing particularly striking about it. But when cut in two it reveals enough beauty to have proved an inspiration to that rare bird, a poetic professor. Coil within coil is seen, each divided into a succession of chambers lined with pearl and separated from one another by thin concave walls of pearl. The last and the largest of these chambers is filled by the short, stumpy body of the animal itself. Its skin builds up the shell by depositing pearly lime, in the same manner as that described for the gastropod. Gradually the chamber is lengthened until it is too long for the body. This then slips forward leaving an empty space behind. After a short while the back surface of the body builds up a new partition and thus a new chamber has been formed.

Year after year beheld the silent toil
That spread his lustrous coil;
Still, as the spiral grew,
He left the past year's dwelling for the new,

Stole with soft step its shining archway through,
Built up its idle door,
Stretched in his last found home, and knew the old no more.

OLIVER WENDELL HOLMES

Each partition wall, or septum, as it is called, is pierced by a hole through which a fleshy cord from the body passes right round the coil until it reaches the first-formed chamber hidden in the centre of the shell. During life these chambers are filled with gas and buoy up the animal and shell so that the whole floats in the water – not on the surface, as in the case of the paper-nautilus. Only the head of the creature is normally on view. This is endowed with a crowd of tentacles surrounding the mouth and a pair of eyes on either side. The latter have no lens, but are constructed on the principle of a pinhole camera. On the under side of the body there is a capacious mantle cavity containing two pairs of gills and a funnel-shaped flap situated in the mouth of the cavity. Rhythmical movements of the mantle walls draw water into the cavity and oxygenate the blood in the gills. The water is then expelled through the funnel which thus acts as an efficient device for jet propulsion which has been in use by this animal and its ancestors for at least 400 million years.

The tentacles and funnel together correspond to the foot of the gastropod, but instead of occupying the under surface of the body they surround the head. This fact suggested the name *Cephalopoda* (*cephale*=a head) for the great division of Mollusca dealt with in this chapter.

The *Nautilus* is the sole survivor of a race which first appeared on the scene in Cambrian times and increased speedily until it reached a climax in Ordovician and Silurian waters. In all of the members of the race the shell was fundamentally a long cone. In some this was straight; in others it was curved, coiled in varying degrees from an open to a closed spiral. More detailed reference may be made to a form from the Ordovician that has been known a long time and is named *Lituites*. That part of its shell that was built up in youth was closely coiled. In later life it stopped coiling and grew straight. This was taken

to be an excellent illustration of the principle of recapitulation, the early coils being reminiscent of a coiled ancestry. The straightening in later life was interpreted as the new development. When, however, in recent years specimens were collected carefully from successive layers of rock a very different story emerged. In the lowest layers, which yielded the ancestral individuals, the shells were straight, not coiled, in early life, and

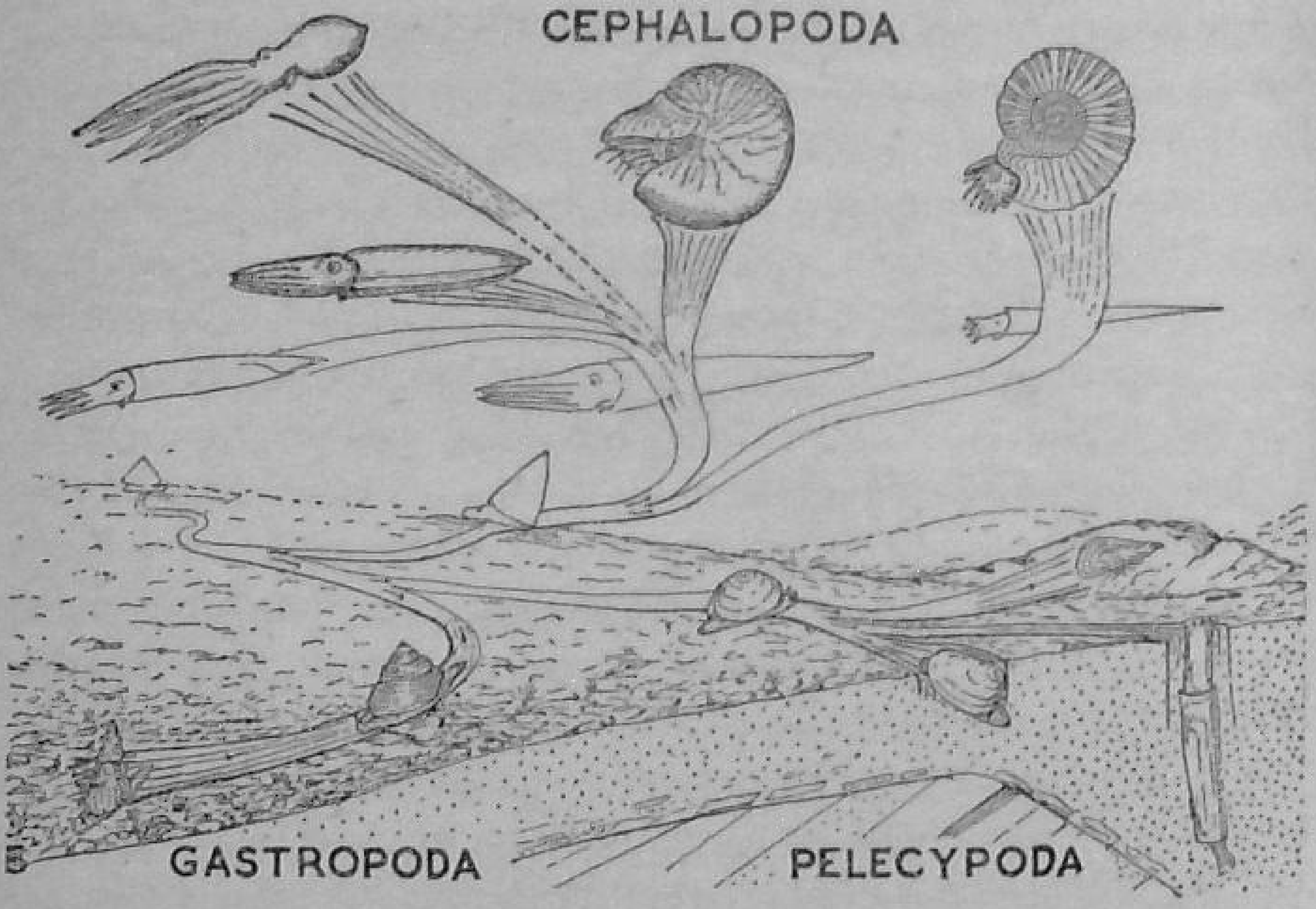


FIG. 16. FLOWLINES OF MOLLUSCAN EVOLUTION

In far perspective is the archetype. *Above*, among the cephalopods and starting in middle perspective, is *Piloceras* leading, on the left, to *Orthoceras*, belemnites, cuttlefish, and nautilus. For the octopus there is no fossil record. *Below*, on the left, are two gastropods with simple ornamentation; on the right is a pelecypod creeping like a gastropod and leading to a normal type, like the fresh-water mussel, a burrowing like the razor-shell, and a fixed type like the sea mussel

the ancestral straight condition was retained in later life. In the topmost layers the whole shell was completely coiled and no trace of the straightness remained – a pretty rebuke written in stone to any who unwittingly assume that Nature is poverty-stricken in her methods of creation. Sometimes, as in this case, she starts off on a fresh track in young creatures and uses youth

to lead the way – a sermon in stone. Usually the shells of the nautiloids were smooth and appear to have been more abundant in North America than in the Old World. Normally they were small, but some of the straight ones were very large. Specimens of *Actinoceras*, for example, have been found which were ten feet long.

The best-known and most abundant of the straight forms was *Orthoceras*. In it the hole that passes through the centre of each septum was larger than in *Nautilus*. In *Endoceras* it was so large that it occupied one-third of the diameter of the septum. Lining the sides of this hole was a fossilized film or skin which extended backwards across several chambers and through several septa. It formed a wide mouthed cone which at its apex narrows down to a thin tube that passes back through all the other chambers to the apex of the shell. It is evident that in this case the body occupied more than the cavity of the last chamber and extended farther back as a cone-shaped hump. In the Ordovician genus *Piloceras* the shell was a short cone with only a few chambers and the conical hump was much larger in proportion. This nautiloid indeed approached tantalizingly near to the condition which, for theoretical reasons, is believed to have existed in the common ancestor of the gastropods and nautiloids. This illustrates a frequent experience in the life of students of living and fossil organisms. The evidence collated by these two classes of investigators sometimes follows converging lines leading to an unknown point – a theoretical conclusion – but the two lines seem to stop just short of joining. Perhaps it is as well that the thrill of making some further discoveries should be reserved for future generations.

Now let us follow the story in the opposite direction, from the Ordovician into succeeding ages. The story of the nautiloids presents a marked contrast to that of the gastropods. They rose rapidly to a climax in early Palaeozoic times, but in the Devonian and Carboniferous they played a diminishing part. After the opening of the Mesozoic only two or three kinds lingered on and to-day *Nautilus* alone survives.

In the nautiloids each septum was concave in front. When the creature died its shell lay upon the sea floor. While it was

being covered with mud or silt some of this made its way into the shell, filling the chambers, and was eventually turned into stone. When the fossil thus formed is found and extracted from the rock the outside shell often breaks away from the solid stony core. On the latter may be seen the edges of the partition walls, or septa, as straight lines encircling the core. In the Devonian rocks fossil remains are found which at first sight closely resemble the nautiloids especially in shape. Closer inspection, however, shows that their septal margins are not straight, but undulating and that the hole through the septum lies not at the centre, but close to the outside margin. These and other features distinguish them and all their descendants from the nautiloids. They are accordingly classed separately as Ammonoidea. The story of these must now be considered.

In the descendants of these Devonian ammonoids the undulations of the septal margins deepened into strong folds which, during Carboniferous times, often became sharply angular, a feature which won for these early ammonoids the designation *Goniatites* (*gonia*=angle). They were small and attractive little creatures that swam about freely and darted in and out among the corals in the reefs. They were lovers of bright clear water, though a few preferred turbid water.

The goniatitic ammonoids were a virile stock which evolved in many directions and gave rise to an extraordinarily varied population in Permian and Triassic times. In addition to developing a complex ornamentation of the surface of the shell the septal margins also became intensely folded and frilled, a condition described as ammonitic. Never in the whole history of the ammonoids was this race so triumphant as during the Triassic period. Towards the end of this period, however, signs of decline set in. The septal margins harked back to the simple folding of the earlier times. Close coiling gave way to uncoiling. Some even became quite straight or developed cork-screw coiling as in the gastropods. A nemesis seemed to strike the race and by the close of the Triassic it was almost wiped out. The mysterious unknown influence which had smitten so many of the other races we have considered smote them also.

From this general calamity a remnant remained and became

the starting-point for a remarkable revival of the ammonoids. The chief of these survivors was *Monophyllites*. It had a smooth, closely coiled shell. The folds of its septal margins had rounded racket-shaped crests and frilled troughs. During the Jurassic period its descendants became multitudinous. They swarmed in both turbid and clear water. Their shells were prettily ornamented and exhibited every degree of coiling. The shell as a whole was sometimes round like a ball, sometimes flat like a disc. The significance of these and other shapes can only be guessed. In size they ranged from diminutive forms, no bigger than a sixpence, to giants 3 feet in diameter.

As with the nautiloids the ammonites were active swimmers in the open sea, and were accordingly widely distributed. Their fossil remains have, therefore, been invaluable for dating rock layers and for correlating these across oceans and continents. Close study of them has thrown many side-lights upon the principles of development and evolution. Unfortunately their usefulness in this respect has been to some extent curtailed by enthusiastic collectors who have christened numerous closely related varieties with very dissimilar names. In literature this practice has hidden their affinities and enshrouded much of their story in obscurity. In general the outline of that story resembles that of the goniatites. They rose to a pre-eminence during the Jurassic and Cretaceous times only a little inferior to that of their Permo-Triassic ancestors. They also in the end harked back to early forms of septal margin and shell shape and indulged in a brief excursion into corkscrew coiling. They then passed away with dramatic rapidity and without any issue.

Reference was made earlier to that most highly organized of all Mollusca the octopus, a creature that sometimes attains giant proportions in modern seas. With its wicked eyes and weird body it has at times fired the imagination of writers of fiction. An unromantic fact about its anatomy, however, is that its chief feature is the possession of two gills instead of four as in nautiloids and ammonoids. It is necessary to mention this because the earliest fossil remains of the race which the octopus represents had a shell strikingly like that of the straight nautilus *Orthoceras*. In view of that fact there was a strong

temptation to conclude that this race descended from the nautiloids. But this difference in the number of gills is decisive and is supported by other facts which cannot be dealt with here. It is more probable that the Palaeozoic ancestors of this race did not make shells and began to do so in Triassic times. The first shells they made were straight and divided into chambers. The hole which passed through the septa lay close to the bottom and not to the top margin of the septum as it did in the ammonoids.

In Jurassic times the pointed end of this shell became completely enclosed by a deposit of lime built, film upon film, into a solid spindle-shaped mass which is called the 'guard'. This feature shows that, unlike the nautilus, the animal did not live inside the shell, but its body completely enclosed it and was thus able to secrete a protective covering around it.

In Jurassic and Cretaceous times the chambered shell became a short, broad-based cone almost completely enclosed by the front end of the guard. The latter was now a massive object of solid lime with a curious resemblance to a cigar in shape. Its fossils are common and well known to some country folk who sometimes carry them about in their pockets as 'lucky stones' or call them thunderbolts. The latter name has been translated into the word 'belemnite'. Belemnites abound especially in clays. They are not very valuable as time indicators because they are so smooth and featureless that it is not easy to distinguish specimens belonging to different periods from one another.

It seems extraordinary that any creature should hamper its movements with such a heavy burden of lime inside its body. However, it seems also that while the ability to secrete lime was a great asset in building up a skeleton or shell, occasionally the process got out of control and lime was secreted far in excess of actual need. The problem then arose of dumping this in a place where it would be least harmful. In belemnites this was found around the outside of the shell.

Belemnites appear to have been most at home in waters where mud was being deposited. Their remains were buried rapidly, sometimes before the body itself had decayed. Consequently fossils are found in which the impression of the soft

body is preserved. From these it is seen that the creature closely resembled the modern cuttlefish. The mouth was surrounded by tentacles. In the cuttlefish these are armed with horn-rimmed suckers, but in belemnites they had sharp horny hooks instead.

Both forms had a jet-propelling apparatus like that of the nautilus, but in addition they had a store of sepia ink which could, if need arose, be mixed with the water in the mantle cavity. This was done when the creature was threatened with attack by an enemy. The inky water was then ejected through the funnel and enveloped the foe in a 'smoke cloud' under cover of which the belemnite or cuttlefish retired in safety. The discoverer of the ink sac in the fossil illustrated his description by drawings made with fossil ink which had been preserved for nearly 150 millions of years.

These exceptionally well-preserved remains prove conclusively that the guard was enclosed inside the body. They also supplied the additional information that the thin upper rim of the chambered shell extended far forwards under the skin on the back of the animal. During Cretaceous times the true belemnites with heavy guards became extinct. Some of their close relatives in Jurassic waters never produced such guards. In one section of these the chambered shell declined and in Tertiary times disappeared. Meanwhile the forward extension of the rim of the shell lengthened and became that thin feather-shaped film of horn which is seen in the squid *Loligo* of present-day seas. In another section the chambered shell remained, but in Tertiary times it underwent a curious multiplication or modification of the septa which spread forwards along the under side of the extended rim and formed that familiar object of the sea-shore known as a cuttle-bone. This, as its name implies, comes from the cuttlefish.

There are no fossil records of the evolution of the octopus. It seems likely that it is the culmination of a long line of cephalopods that never produced any hard parts, but which, nevertheless, attained in this strange creature, the largest size and the highest degree of organization exhibited by that great order of living things, the Mollusca.

31

LITTLE BUT IMPORTANT FOLK

AFTER a rough sea the beaches are often strewn with masses of seaweed and sea mosses and entangled star-fish, sea urchins, and even fishes. Some of the sea mosses, such as the seamat (*Flustra*), have a superficial resemblance to seaweeds, but are easily distinguished by their fawny colour, horny substance, and slightly roughened surface. On closer inspection, especially with a lens, this surface looks like a very fine network each mesh of which is really a minute chamber, the home of an equally minute animal. The seamat is in fact the supporting framework of a colony made up of a great multitude of these tiny creatures. Unlike the individuals in the hydroid colonies of the Coelentera these are independent of one another and have a bodily structure comparable in complexity with that of a very young mollusc or echinoderm. The general name for this interesting group of animals is Polyzoa.

Each colony starts as one individual which, when it hatches out of the egg, is a free-swimming larva like that of the worms and molluscs. After a while the larva settles down and becomes fixed to the surface of a stone or other solid object. There it grows and gives origin to one or more buds. Each bud in turn grows and buds and so a colony comes into being. In primitive forms the successive buds and chambers follow one another in a single file, which presently divides into two files, or branches. This process is repeated indefinitely. In others the buds arise in twos, threes, and greater numbers and form correspondingly broad branches. In some types these eventually become so broad that their edges meet and thus the colony becomes a sheet of densely crowded chambers each with its own little inhabitant. These colonies sometimes creep over or even encrust the surface on which they grow, or they stand up like a seaweed in the water.

In early Palaeozoic times, the Polyzoa made extensive use of

lime in building their colonies, which were accordingly more massive and bore a striking resemblance to elegantly branched corals, or to miniature editions of the honeycomb coral. They then made an important contribution to reefs and the formation of massive limestones.

Many of the Palaeozoic types declined and disappeared at the close of that era, but some survived and provided a basis for a vigorous revival in late mesozoic times. After this they continued to flourish until the present day.

The lampshells or Brachiopoda have much in common in bodily structure with the Polyzoa, but in them the individuals live singly and not in colonies. They bear a superficial resemblance to the mollusc, but anatomically they are quite different.

Each individual is enclosed in a shell made up of two valves which, instead of covering the right and left sides of the body as in the pelecypods, cover the upper and the under surfaces. The animal lives attached to another shell or a stone by means of a fleshy stalk at its front end. This emerges from the shell either between the valves or through a hole at the tip of the lower valve. The shells are usually half an inch or an inch long and their abundance as fossils, elegance of form, and beauty of ornamentation make them favourite objects for collectors. They are also very useful to serious students working either on problems of rock succession or on the principles of development and evolution.

Perhaps the most interesting of living brachipods is *Lingula*. This, as its name implies, has a tongue-shaped shell. It lives in the mud, or silt, on the floor of estuaries in the Far East, and has a long contractile stalk by which it is anchored to the bottom of the hole in which it lives. By means of this the animal can push itself up into the water above or withdraw itself into its home. An extraordinary feature about the history of *Lingula* is that fossil shells closely resembling, if not actually identical with, it are found in rocks of all ages back to the Cambrian. For 500 million years while other brachipods, and, indeed, many other types of animals have appeared, run their course, and vanished; while continents have rocked up and down and mountain chains have been exalted to the skies and

then laid low, this little creature has pursued its course placidly, and practically unchanged. An emblem of stability in an ever-changing world, but a thorn in the flesh to the early upholders of the doctrine of organic evolution. *Lingula* is an ideal example of a long-ranged form.

The shell of *Lingula* and of its early Cambrian allies consisted of horn, slightly impregnated with phosphate of lime. This fact supports the suggestion that the earliest material used by animals for protecting or supporting their bodies was of a horny nature, and that the almost exclusive use of lime came later.

Of the four major groups into which brachipods are classified three were already represented in the lowest beds of the Cambrian. This indicates that they must have had a long history and have become well established in the Pre-Cambrian seas. These groups reached their climax during the Silurian, when they exhibited a wide range of forms. They continued to flourish during the Devonian, and, though they began to decline in the Carboniferous period, it was then that, strange to say, they gave rise to *Productus gigantea* which as its name implies was the largest of all known brachipods, for its straight hinge was a foot and even more in length. The finest collection of specimens of this giant that the author has ever seen was in a quarryman's garden in Derbyshire in a large rockery which consisted entirely of *P. gigantea.* All three groups declined rapidly at the end of the Palaeozoic, but a few odd representatives have lingered on and live in existing seas.

The fourth major group put in its first appearance in Ordovician times. These are characterized by the possession of a really efficient arrangement for the passage of the stalk through the shell.

This group includes three main strains. The first is represented in modern seas by an attractive little shell called *Rhynchonella*, because the front end of the lower valve is shaped like a beak. The surface of the shell is ornamented with radiating ribs. It also is an example of a long-ranged form for it has undergone comparatively little change since Ordovician times. The second strain, on the other hand, underwent many and

rapid changes with the passage of the Silurian. During the later Palaeozoic it declined and became extinct in the Jurassic period. *Spirifer* is the best-known member of this strain. When its neatly ornamented shell is removed it is seen to contain two very delicate spirals spun out of lime. The third strain appeared in the Devonian and evolved steadily until the Jurassic when a rich and varied assortment of kinds was produced. They were relatively abundant and have been found very useful by geologists in correlating the Jurassic and Cretaceous rocks of different countries. They sank to insignificance during the Tertiary and a few survive to-day, particularly in Australian seas. This last fact should be linked with the survival of *Pleurotomaria* in the same waters.

32

MAN'S RIVALS

Of all the invertebrates none play such a large part in human life and activity as do the Arthropoda. Indeed there are those who say that the greatest conflict that is going on in the world to-day is Man versus Arthropods. In tropical lands dense clouds of locusts darken the skies and consume his crops. Mosquitoes and tsetse flies have in the past carried on disastrous germ warfare and devastated large areas with diseases that have laid men low and slain thousands. In cooler realms the contest is not so dramatic or fatal, but even there it proceeds ceaselessly. The caterpillar and the canker worm spoil his fruit crops or devour his vegetables. The spider frightens or teases the housewife; the wasp, her children; and the flies her baby. On the other hand bees fertilize man's flowers and harvest his honey. Together with the ants they have supplied sages with illustrations of industry and wisdom. It comes as no surprise, therefore, to learn that of all Nature's experiments with the invertebrates, dealt with in the previous pages, none was so successful as the evolution of the Arthropoda and none resulted in such highly organized creatures.

Reference has already been made to those main features which these creatures have in common with one another, and which are most useful to the students of fossils. Their bodies are enclosed in a horny-looking substance known as chitin produced by the outer surface of the skin. In some kinds, as, for example, the crabs and lobsters, this is hardened or strengthened by impregnation with lime. Their bodies are to some extent segmented and, like their legs, are rendered flexible by means of joints where the chitin is unchanged and soft.

This rigid, closely fitting covering of the body presents to the animal the same problem as growing boys or girls do to their parents. The body grows, but the clothes do not. The only thing to do is to cast the old clothes aside and buy new ones. The arthropods, however, have a slight advantage. When they feel the fit is getting a little tight they retire from active life, cast the old covering, swell rapidly, and then secrete more chitin. This hardens rapidly and makes a new garment large enough 'to allow for growth'. This process is technically known as ecdysis, and is of great value to the geologist. Both the old cast-off garments, as well as the new, are frequently preserved as fossils and furnish material for studying the growth and life history of the individual.

The great division of the arthropods that is represented by lobsters and crabs is known as the Crustacea. The vast majority of the Crustacea are small or even minute, but they make up in numbers what they lack in size. They swarm in the surface waters of the oceans and furnish food for fish and even for whales. They vary greatly in structure and appearance. Some of the lowlier types were represented among the fossils found in the Middle Cambrian rocks of British Columbia. This fact indicates that they must have played an important part also in the waters of the Pre-Cambrian seas. They are found occasionally also in rocks of all ages up to the present time.

A few of the larger and more highly developed Crustacea have been found in Devonian and Carboniferous rocks, but it was not until the opening of the Mesozoic era that Crustacea having a more familiar aspect appeared. At first these all resembled the lobsters and the shrimps in having long narrow

bodies divided into two parts. The front half, which was completely enclosed in a continuous covering or carapace, carried on its under surface five pairs of walking legs, a mouth armed with jaws which were only highly modified legs, two long feelers, and a pair of eyes on stalks. The hinder half or tail was divided into segments each provided with a pair of feathery legs used for swimming. In one type that appeared in the Trias the carapace was broad and depressed. This broadening increased in some of the Jurassic Crustacea and the tail was reduced. During the Tertiary this process culminated in the production of genuine crabs in which the small tail, known to a cook as the 'apron', was turned forwards and hidden underneath the carapace.

Another great division of the Arthropoda consists of the trilobites, a most attractive lot of creatures that ran their course in Palaeozoic times. They are so called because of the presence of two grooves which run the whole length of the body on the upper side, thus giving to it a threefold division. The body is also divided transversely into a number of segments. The central lobe contains the internal organs and is the body proper. The side lobes are thin extensions of its edges and hide from view the many and complicated appendages which were attached to the underside of the body. Each appendage consisted normally of a jointed walking leg, an outer leg which carried a feather-like fringe adapted for swimming, and a small nondescript structure which is believed to have functioned as a gill.

At the front end of the body five or more segments were fused into one piece, the head. This carried on its upper surface a pair of eyes which, like the eyes of a fly, were made up of a mosaic of minute lenses. On its under side it carried the mouth, four pairs of legs used as jaws, and, in front, a pair of long feelers. At the hinder end a variable number of segments were fused and formed a tail-piece.

There is every reason to believe that trilobites descended from worm-like ancestors during Pre-Cambrian times, and advanced so far in their evolution that no less than eight distinct types already existed when the Cambrian period opened.

Trilobites were abundant in all the older Palaeozoic seas throughout the world. During their prime they were the sea lords. Usually they were small, only a few inches long, but some attained a length of several feet.

A study in the modes of life led by existing Crustacea, and of the associated modifications of the different parts of the body, has furnished interesting clues to the habits of the trilobites. In the majority the eyes are situated on the upper surface of the head. This fact, together with possession of walking legs, suggests that normally they lived on the floor of the sea where the light came only from above. Here, with their long feelers, they searched for food, small worms, and the like. Nevertheless they also possessed swimming legs by means of which they rose from the floor and skimmed through the water above it. Like shrimps and lobsters they could flap their tails sharply forwards and dart rapidly backwards, a movement that was useful when they were suddenly confronted with danger. They could then drop to the floor and hide in the mud. A few burrowed, like moles, in the mud and also, like them, they became blind. The body shape became streamlined with smooth surface and pointed ends. In others, again, numerous long thin spines covered the body, probably enabling them to float about in the water, like dandelion-down in the air, and so they drifted about whither the currents took them. It is not surprising that the fossil remains of such abundant and mobile creatures have proved invaluable to geologists in dating and correlating rock in widely separated exposures.

The story of the trilobites illustrates the normal sequence of stages in racial history. First there was a period of obscurity, about which usually very little is known. Next came a period of progress up to an acme in early Palaeozoic times, when new species and genera were being continually evolved until every conceivable shift for a living in the sea was being tried. The third stage was one of decline when new species rarely appeared and old ones died out from time to time. This happened to the trilobites during Devonian and Carboniferous times. Finally the last member of this great race disappeared in the Permian. The extinction of a race is never wholesale or catastrophic, but

takes place in the way just described – sometimes slowly and steadily as with the trilobites, and at other times rapidly as with the ammonites in the Trias and the Cretaceous.

One word more about these attractive little creatures. Among known animals they come nearest to fulfilling all the conditions required for the ancestral stock of the Insects. Probably among the shifts for a living that they tried at the time of their acme some found their way on to the dry land. There they met with success because they were already endowed with certain advantages. Their bodies were enclosed in an impervious covering which could shield them from being dried up like jelly-fishes stranded on a beach. They had numerous legs that could support and carry the body when they ventured forth from the water with its buoyant influence. All that remained was for the gills to be kept moist for taking oxygen from the air. That this could be done is proved by the existence at the present day of land crabs that live on some of the tropical islands. Meanwhile a new and better device for breathing air could be evolved. Direct fossil evidence for this is, as yet, not forthcoming. The finding of that is a thrill reserved for some future collector and student of fossils.

The third great division of the Arthropoda is the Arachnida (*arachne*=spider) to which the spiders and scorpions belong. Spiders are the most highly specialized of the arachnids, but they have one quite obvious feature which characterizes all arachnids and readily distinguishes them from the other arthropods: they have four pairs of legs. Shrimps, centipedes, butterflies suffice to remind us how very variable the number of legs is among other arthropods. In the arachnids, which range in time from the Cambrian to the twentieth century, there have always been four and only four pairs of legs. In addition they usually have on the front of the head a pair of limbs provided with pincers or other device for catching and holding the prey upon which they feed.

The only marine arachnids living in modern seas are found along the shores of North America. The best-known and largest of these is the king crab, *Limulus*, which attains a length of 2 feet, or more. Its body is divided into three parts. The

front part is half-moon shaped with a pair of eyes above and a mouth below. The latter is surrounded by the legs, the basal portions of which also function as jaws. The middle part of the body is triangular and carries at its tip a long spine which is the third part. Fossils of *Limulus* are found in rocks of various ages as far back as the Trias, so that for a period of 150 million years it has undergone only an inappreciable amount of change.

When *Limulus* first hatches out of the egg the middle part of its body is divided into eight segments and its tail spine is diminutive. At this stage it is so strikingly like the fossil *Prestwichia*, that there can be no doubt about their close relationship to one another. *Prestwichia*, which is relatively common in the Carboniferous coal measures, is only about an inch or two long and represents a series of little arachnids of which three genera were among the fossils found by Walcott in the Middle Cambrian of British Columbia. They, like the trilobites with which they have some features in common, must also have lived during Pre-Cambrian times. The king crab, therefore, belongs to a very ancient and aristocratic race.

Living alongside this series of smaller animals and closely allied to them were a number of much larger forms. The best known and most representative of these was *Eurypterus*. It was normally about 1 foot long. In general appearance it was like a scorpion, a fact which has earned for it and its relatives the popular name of sea scorpion. The head was almost rectangular in shape with the usual complement of eyes, mouth, pincers, and four pairs of legs. The end sections of the last pair of legs were flat and paddle shaped, for *Eurypterus* was an active swimmer. The rest of the body was divided, as in the scorpion, into thirteen segments. In both these animals the front segments were broad, the back ones narrow, and the last a spine.

The earliest-known relatives of *Eurypterus* lived in the Cambrian seas and exhibit features which suggest that they were derived from the same Pre-Cambrian ancestral stock as the trilobites. In Silurian and Devonian seas the eurypterids were world-wide in their distribution and attained the climax of their evolution. *Stylonurus* was three feet long and had elongated spidery legs. *Pterygotus* grew to a length of 8 feet and

breaks a record by being the largest known arthropod. They were the most fearsome and predacious creatures living in those ancient seas. It is impossible to conjecture how long they would have remained the war-lords of the marine world had it not been for the appearance on the scene of the more efficiently constructed vertebrates, which competed with them in this the first round of the contest and were successful. These arachnids, however, were not extinguished very rapidly, for many still survived in the fresh-waters of the Carboniferous world.

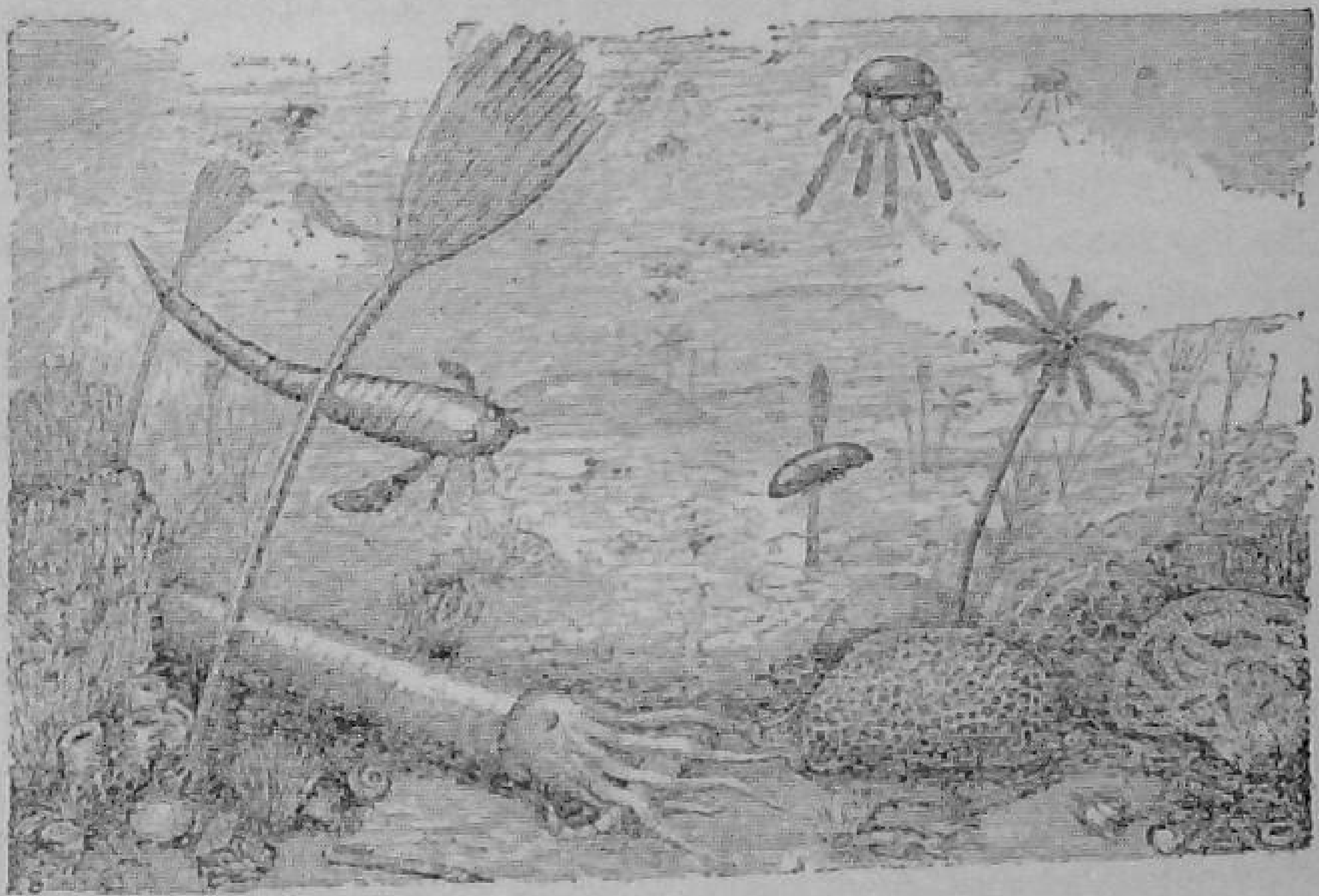


FIG. 17. THE NATURAL HISTORY OF A SILURIAN SEA

Colonies of graptolites floating. Sea scorpion (*Eurypterus*) and trilobite swimming. On the floor, orthoceras; honey-comb, chain, and other corals; stone lilies, lampshells, gastropods, and various seaweeds of the *Laminaria* type

An insignificant but important group of small arachnids existed in the Upper Silurian seas. It was represented by *Palaeophonus*, one of the earliest-known scorpions. It probably migrated to the land during Devonian times, for in the Carboniferous rocks of the United States fossil remains of true air-breathing scorpions have been found. A reference was previously made to the finding of scorpions also in a Triassic oasis. It is a fascinating idea that scorpions have existed with

but minute changes of bodily structure for 300 million years. A slight modification converted their gills into lungs, and thus opened out to them a long, long career as air-breathers and land-dwellers.

In bringing this summary of the evolutionary history of the arachnids to a close reference should be made to two interesting little fossils from the coal-measures of Shropshire and Illinois which were both of them air-breathers. One, *Protolycosa*, was the forerunner of the spiders. The other, *Eophrynus*, was one of that group of pests known as mites. It was not, however, the earliest of its type, for the Middle Old Red Sandstone chert from Rhynie in Aberdeenshire also yielded a mite. This has the distinction of being the earliest-known air-breathing animal.

It is a natural step now to pass from spiders to flies, from arachnids to insects. In the latter the body is divided into three parts. The middle part or thorax carries three pairs of legs and sometimes one or two pairs of wings. The earliest fossil insects hitherto found come from the Carboniferous coal-measures. These include forms closely allied to cockroaches, locusts, may-flies, and dragon-flies. The fact that all these had wings and could fly implies a long previous history dating back into Devonian and possibly Silurian times, during which their ancestors first became adjusted to life on the land as air-breathers. Some of these then learnt to fly by climbing up *Psilophyton* and other miniature tree-like plants. Thence they launched forth into the air and glided by means of fixed wings projecting from the sides of the body. At first there were a number of these wings attached to the sides of a succession of the segments of the body. One or two pairs, however, increased in size and extent at the expense of the rest. At first they were fixed and functioned merely as gliding planes. Later they became movable and were true wings. Some of the dragon-flies had gliding planes or wings that stretched 2 feet from tip to tip. During the Permian, forerunners of caddis-flies and butterflies appeared. Indications of bees and ordinary flies have been found in Mesozoic rocks, but it was not until the Tertiary that these began to approach their present variety, numbers, and distribution.

33

THE SILVER HARVEST OF THE SEA

THE heading of this chapter comes from the Fisherman's Hymn. Even those who have never watched the fishermen unload their haul at the docks are sufficiently familiar with the fishmonger's stall to appreciate that description. Unfortunately that stall with its load of strange creatures – cockles, whelks, prawns, and crabs, as well as fishes – is the only peep at the teeming life of the sea that the majority of people ever get. It is into this strange unfamiliar world, from which this harvest is gathered, that we must now penetrate yet once more in order to spy out some of the details that make up the story of the ultimate origin of land vertebrates and, therefore, of man.

In the previous pages it has been seen that practically every important division of the invertebrates is known to have existed in Cambrian seas and possibly also in the Pre-Cambrian. The first known traces of the vertebrates, however, appear later, for their remains have been found in the Ordovician of Russia and Colorado under conditions that suggest that these earliest fishes lived in fresh water. Much more complete remains have been found in the marine rocks of the Upper Silurian of Europe and North America. These include the fish *Cephalaspis* in which the head was protected by a strong bony shield. On the inside surface of this impressions have been found which were made by the brain, nerves, and blood vessels. From these much has been learnt about the anatomy of the fish. Like the sturgeon it grubbed about on the sea floor and sucked up its food with its protrusible mouth which was without jaws. The side walls of the mouth cavity were pierced by a series of holes. In the absence of jaws and the presence of these holes it resembled the lamprey, an eel-like fish that lives in the rivers and sea to-day. The lamprey, like every other fish, breathes by 'drinking' water continually and expelling it through these holes, the lining of

which is ruckled and richly supplied with blood vessels, and functions as a gill. The walls between these gills openings are supported by a framework of rods made up of a gristly looking substance called cartilage. The main vertical rods are called gill arches and, as will be seen presently, play a very important part in the evolution of the fishes.

Two other groups of jawless fishes existed at the same time as the cephalaspids. In one the front of the body was enclosed in an armour of stout bony plates. In the other the body was shaped more like a normal fish and was covered with numerous small bony scales. Though these small, very primitive, jawless fishes made up a large part of the fish fauna in those Middle Palaeozoic seas, no remains of fishes related to them have been found in later rocks. Nevertheless, such must have existed throughout Mesozoic and Tertiary times for they still survive in the lampreys and hagfishes of modern waters.

While these jawless fishes were still common, fishes with true jaws came upon the scene and, naturally, soon completely overshadowed their primitive contemporaries. Some of them had both head and trunk enclosed in stout bony armour. Normally they were no more than 2 feet long, but one, called *Dinichthys*, was a monstrous giant of which the head alone was 3 feet long. With enemies like this in their midst it is not surprising that even the giant sea scorpions, the eurypterids, either perished or fled for refuge into the shallow waters of the rivers and lakes. Even there they were followed by diminutive relatives of these fishes whose fossil remains were referred to in an earlier chapter as being so useful to the geologist in his work upon the Old Red Sandstone and Devonian.

In the sea, as in human affairs, the race was to the swift and not to the merely strong. By the end of the Devonian these armoured fishes died out, but their more agile, less encumbered companions advanced and gained dominion in the seas. Indeed they became the ancestors of all the vertebrates that exist to-day whether on land or in the sea. Their success was largely due to two factors – to the possession of larger mouths strengthened by powerful jaws and paired fins by means of which they could guide and control their movements efficiently.

In order to understand the origin of these jaws it is helpful to glance at the modern shark. In this the gill clefts in the sides of the mouth cavity are five in number. These are large and, as the word cleft implies, are like slits. They lie parallel to one another in series behind the mouth. Just over the corner of the mouth there is a small round hole, the spiracle, which serves a similar purpose. The walls between the clefts are supported by vertical bars of cartilage each of which is made up of four pieces. The two middle pieces are bigger than those above and below, and are much enlarged in the first arch which lies immediately behind the spiracle. The upper one of the two is attached by one end to the base of the skull and by the other to the angle of the jaw. It thus acts as a device for holding this steady and in position. The jaws themselves consist of two similar, but still stouter, bars of cartilage which lie practically horizontally along the margins of the mouth. The extinct genus *Acanthodes* belonged to a family of sharks which flourished in the Devonian seas and lasted on into Carboniferous and Permian times. Specimens have been found in which the slightly ossified skeleton is well preserved. In these the spiracle was a normal gill cleft separating the first arch from the angle of the jaw. Evidently, in later sharks, the mouth had become bigger by extending its corners backwards. In doing so it had crushed the lower part of this gill cleft out of existence, leaving only the upper part as the spiracle. At the same time the jaws joined up with the arch and thus gained additional support.

This discovery confirmed an old suspicion that some descendants of the jawless fishes had acquired jaws by a backward extension of the corners of the mouth accompanied by the incorporation of gill arches as a supporting framework for its margin. In this connexion the fossil remains of *Kieraspis*, from the Upper Silurian, are important, for they show that in this jawless fish there was yet another gill cleft in front of the spiracle. Presumably it was the cartilaginous arch in front of this that in the course of evolution became the jaws of all other vertebrates. Here is an excellent example of the principle that progress in evolution is often made by changing the function of an important structure or organ. It is so in human affairs.

The 'Heath Robinson' devices of an ingenious handyman are but minor examples. Those readers who are engaged in industry will no doubt call to mind more important ones.

In all the fishes so far considered the main organ of propulsion was a long flexible tail provided with a deep fin usually along the under edge. This was swished from side to side like a man sculling a boat along with one oar. As long as the fish was coasting along quietly it would glide round to the right or left by using this tail fin as a rudder. It could even use this as a gentle brake. But for turning sharply or braking rapidly some better device was required, and that was supplied in the course of time by the evolution of paired fins. The story of these must now be told.

Here again the new need was met by changing the function of an old organ, traces of which have been detected in very primitive fishes and in the early growth of more advanced ones. These indicate the former existence of a pair of keel-like ridges running along the sides of the fish's body. In the Upper Devonian shark, *Cladoselache*, the middle portion of this ridge is absent, but the front and back portions remain as broad-based lobes projecting from the fish's sides. The front one was much larger than the back, but both obviously served no other purpose than that of a keel. Judging by the conditions in other fossil fishes the tip of each lobe broadened considerably while its base of attachment to the body became very narrow. In other words the keel was turned into a fin. This could still be used as a keel, but now the base was little more than a stalk by means of which the flat surface of the fin could be rotated and placed athwart the water as it streamed past the moving fish. When both right and left fins were stuck out in this way the fish came rapidly to a standstill. With the fins of only one side projecting, the fish could execute a sharp turning movement towards one side. With such perfected control of rapid movements the small early sharks could elude pursuit. They could snatch food from in front of the mouth of even a *Dinichthys*, or pursue and eat its fry.

Though the first sharks retained traces of bone, inherited from their armoured but jawless ancestors, they soon lost these,

and their skeletons became wholly cartilaginous. Their skin was, however, furnished with numerous little scales having much in common with an ordinary tooth. That is to say they consisted largely of a bony material called dentine which was covered on its outer surface with hard shiny enamel. Where the

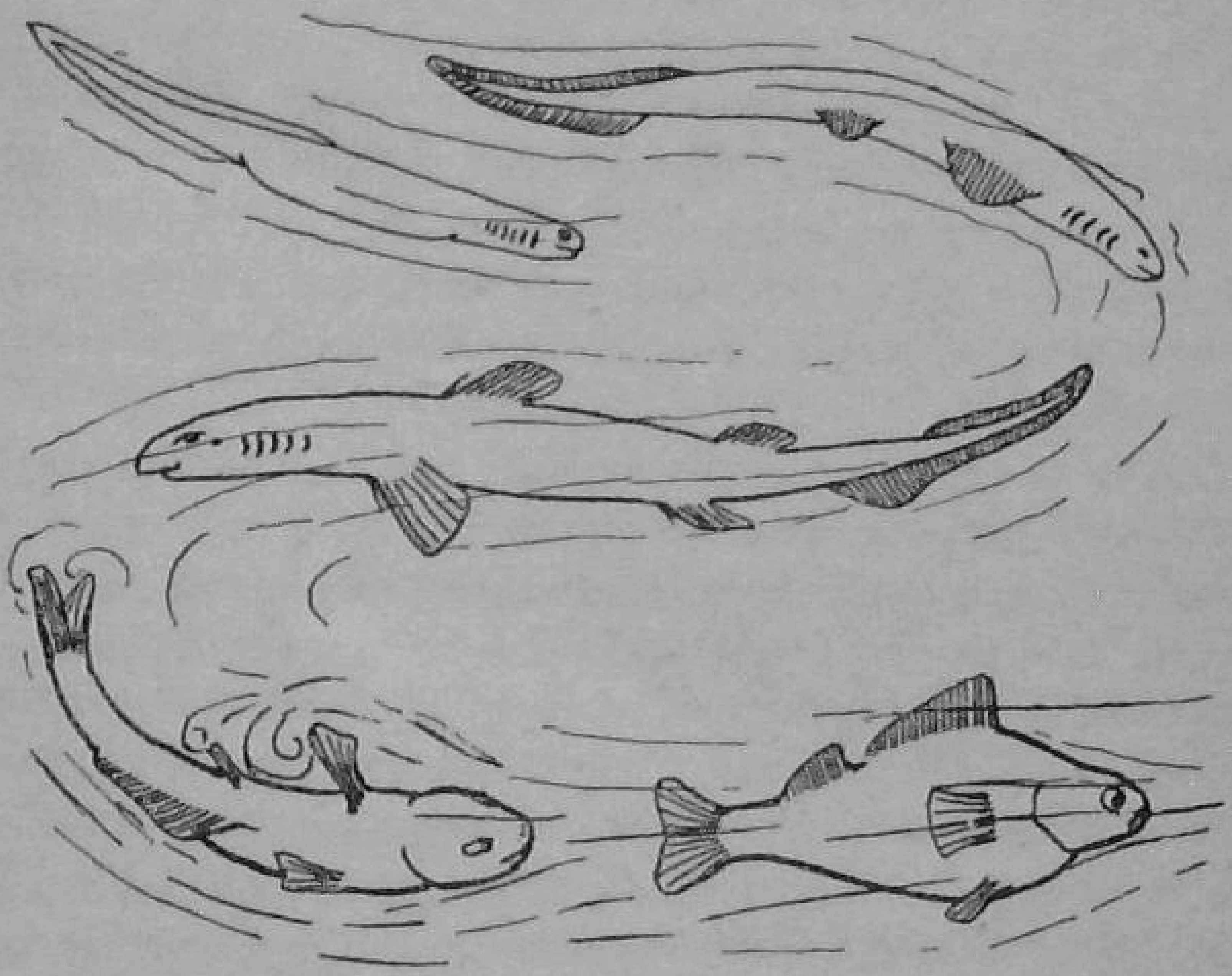


FIG. 18. THE EVOLUTION OF FINS AND FUNCTION

From continuous lateral keels, through lobe-shaped keels, to mobile fins that can be used to act as brakes and rudders

skin passed over the jaws into the mouth these scales did in fact become teeth. Since they are the most durable parts of the body they are frequently found as fossils, but the rest of the body is rarely preserved either in whole or in part. Teeth are common in Mesozoic and Tertiary rocks, and generally conform to one or other of two types. In one type the crown of the tooth is armed with one or several long sharp piercing points, well suited for seizing and holding slippery prey. These are the relics of genuine sharks – lithe, swift, predacious. In the other type of tooth the surface is rounded or flat. They are usually large and are fitted against one another like slabs of stone in a pavement. They covered both the upper and the lower

jaws, which were consequently well equipped for crushing the hard shells of the molluscs on which they fed and for which they hunted on the sea floor, as do the existing skates and rays.

Though sharks play a prominent part in tales of the sea they are, in fact, only a small minority of the marine population. The great majority, like the herring, have skeletons made up of bone. As building materials, for such a framework, cartilage and bone may be compared with wood and steel. The one is clumsy, the other combines great strength with elegance. The story of the bony fishes is fundamentally the story of the discovery and exploitation of bone as a skeletal material.

In the earliest fishes there was no real 'backbone' in the commonly accepted sense of the term. There was, however, as in the little living fish *Amphioxus*, a long flexible rod, the notochord, consisting of material less brittle than cartilage. It stretched the whole length of the body from the tip of the tail to the middle of the head. It is always present in the early development, not only of fishes, but of every other vertebrate including man. It is the foundation around which the skull and vertebrae develop and upon which the limbs, both legs and fins, are hung. As development and evolution proceed, these other parts of the skeleton are first blocked out in cartilage, which is then gradually replaced by bone. Such bones are described as cartilage bones to distinguish them from membrane bones, strong thin sheets which first appeared as ossifications in the skin but subsequently sunk in and became intimately associated with the rest of the skeleton. With this outline of the evolution of the skeleton in mind we must turn to the story of the bony fishes as revealed by fossils.

As with the sharks, so with the bony fishes, the evolution of fins played an important part. So much so indeed that Nature seems to have tried out many experiments with a view to discovering the most efficient plan of structure. Our attention must necessarily be confined to the two which ultimately proved to be the most successful for her purpose. The characteristics of the two types are well displayed in the very familiar herring and

in the much less familiar *Ceratodus* or mudfish of the Australian rivers. In the former the fins consist of a broad thin membrane entirely supported by slender bristle-like rods known as fin rays. These converge and thicken slightly towards the side of the body where they are anchored to bones imbedded in the body wall. In *Ceratodus*, however, a long fleshy lobe projects from the side of the body carrying along its margin a thin membrane strengthened by delicate fin rays. Internally this lobe is supported by a central axis and several short branches of cartilage bone. These two types of fin, so fundamentally different in structure, characterize two divergent and quite distinct lines of descent culminating on the one hand in the rich harvest of the sea and, on the other, in the fisherman who now reaps that harvest. These two stocks of fishes are classed under the names of Actinopterygii (ray-finned) and Crossopterygii (fringe-finned) respectively.

The sturgeon is a degenerate survivor of the earliest 'ray-finned' fishes which flourished in the late Palaeozoic seas. The best-known fossil is that of *Palaeoniscus*, an agile fish of normal shape and size. It had a long mouth armed with a long array of sharp teeth. The gill slits, as in modern fishes, were shielded by a gill cover, a large flap of skin supported by thin membrane bones. The head was protected by similar bones with prettily sculptured surfaces. The trunk and tail were completely mail-clad with thick rhomb-shaped ganoid scales coated with enamel or ganoine. The end of the tail was tilted upwards and carried a large forked fin along its under margin. The palaeoniscid fishes were common in Carboniferous and Permian times and were equally at home in fresh and in salt water. Their remains are often found in coal-measure shales. *Platysomus*, a close ally, was a very deep-bodied fish shaped like John Dory.

While the palaeoniscids were declining in Mesozoic times their place in nature was being taken up by another race which had evolved from them. In this the efficiency of the tail was improved by a shortening of the tipped-up end and the shaping of a more symmetrical fin. These fishes were still covered with ganoid scales. They included two main types – large-mouthed

predacious forms and small-mouthed fishes with blunt teeth well suited for crushing vegetable food and small molluscs. They exhibited a wide range in shape of body, like that seen in modern fishes, in accordance with the varied modes of life they adopted. The ganoids remained dominant until Middle

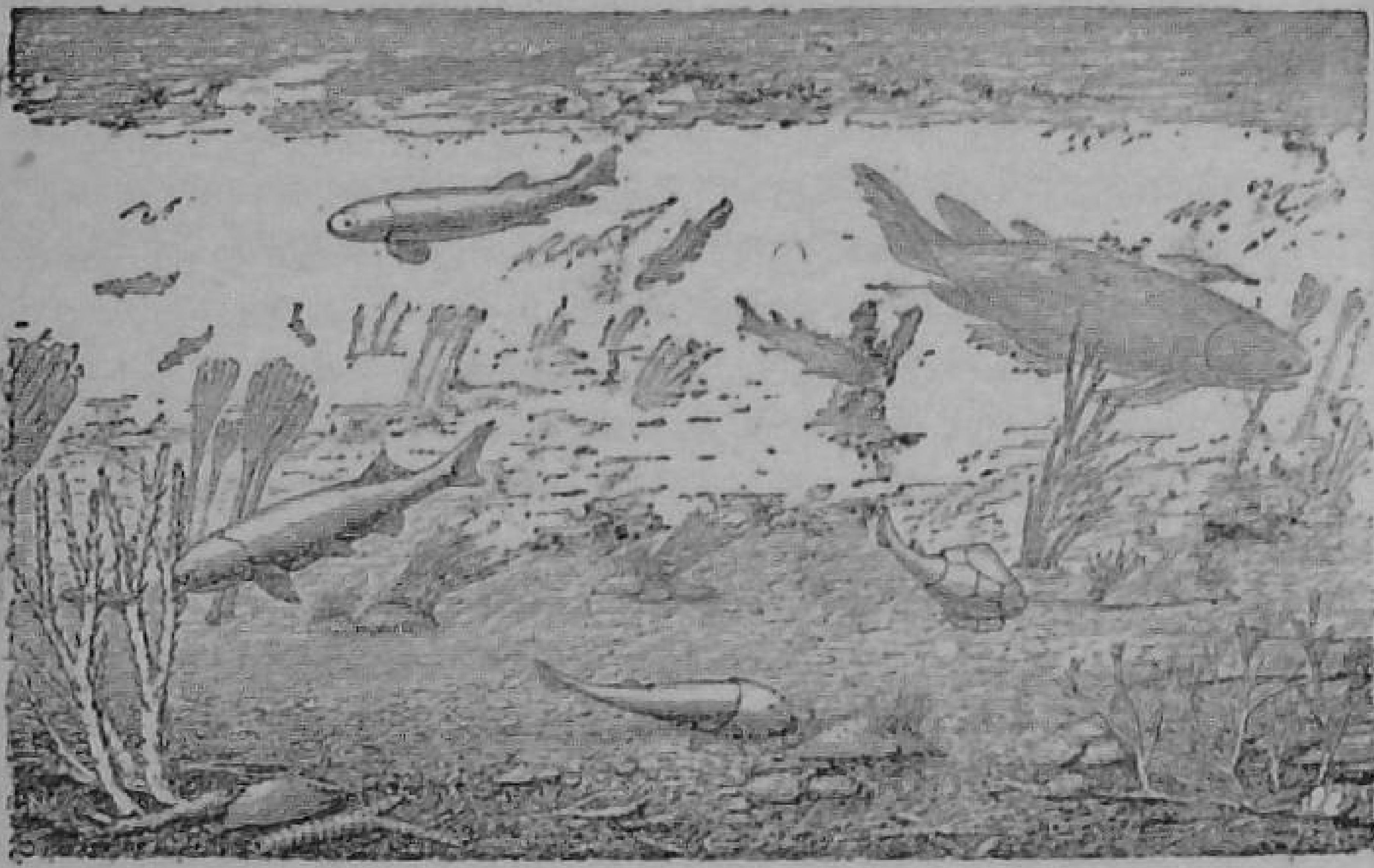


FIG. 19. FISHES OF OLD RED SANDSTONE TIMES

Left: Osteolepis and a palaeoniscid, *Cheirolepis*. *Right: Holoptychius*. *On the floor: Cephalaspis*. The plants in the foreground are *Arthrostigma* and *Zosterophyllum*; elsewhere is an ally of the seaweed *Laminaria*. Scattered about is débris from *Calamophyton* and other land plants

Tertiary times when they began to decline rapidly. They are still represented by two fishes, the garpike and amia which live in the fresh waters of the United States.

During Jurassic times a few fishes showed a tendency to shed their medieval characteristics and assume modern ones. Thus, for instance, their scales lost the enamel and became round and thin. Instead of lying side by side with their edges in contact, they overlapped one another like slates on a roof. The skeleton became completely bony, a feature which gave rise to the name Teleostei for this new race.

During Cretaceous and Tertiary times the Teleostei moved rapidly towards completely ascendancy. Of the many changes of structure that took place reference need only be made to the fins. These underwent little change in themselves but their positions in relations to one another altered in such a way that they came to lie close together in the same vertical line and consequently served more efficiently as a fulcrum around which the fish could execute rapid turning and darting movements. Space will not permit an account of their multitudinous adaptations of form and habit. It must suffice to say that these compare favourably in wonder and beauty with those seen in the birds of the air and the flowers of the field.

We must now hark back to the Devonian and pick up the other main thread of this fisherman's story which deals with fishes that had fins supported by a stout fleshy axis. Superficially they did not differ strikingly from the early ray-finned fishes. Among themselves they showed the same general division, seen in the other groups, into large-mouthed predacious fishes, and small-mouthed vegetable and shell feeders.

In the latter the crushing teeth were on the roof and floor of the mouth. They are represented to-day by the mud-fish, *Ceratodus*, that lives in the rivers of Central Australia. During the dry season these rivers shrink and break up into a series of stagnant pools with water too foul to aerate the blood in the fish's gills. *Ceratodus* is, however, endowed with lungs and is able to breathe air until the rains return and flush the river channels with fresh water. This fish and its allies are accordingly classed as Dipnoi, double breathers. The Dipnoi remained prominent among the fishes throughout late Palaeozoic times, but dwindled rapidly during the Permian. Fossil teeth of *Ceratodus* are found in the Triassic and later rocks.

In the other division of the fringe-finned fishes the mouth was large and armed with numerous small teeth around its margins. A typical member of this division was *Osteolepis* which flourished from the Middle Devonian until the end of the Permian when it disappeared. At the end of the Devonian this stock gave rise to a curiously interesting type represented by *Coelacanthus*. Among other peculiarities this had a stumpy

symmetrical tail and fin. These fish were quite small, but they lasted a long time. They were still quite vigorous in Cretaceous times. It used to be thought that they then became quite extinct. In recent years, however, world-wide interest was aroused by the capture of a living coelacanth in the Indian Ocean. This has been named *Latimeria*.

Other members of the osteolepid stock took part in the most epoch-making event, not merely in the history of fishes, but of the vertebrates as a whole. At the close of the Devonian and Old Red Sandstone period some of these fishes, living, it may be, under conditions similar to those in which *Ceratodus* lived, also developed nostrils and lungs. In searching for other pools of water as refuges from drought or because of other reasons, as yet not imagined, they used their stout fleshy fins for getting a purchase on the slippery mud banks and their flexible tails for wriggling over the ground. Whatever may have been the precise means they used or the precise urge that impelled them, they found out an entirely new way of life, the life upon land. They were the pioneers that opened out quite a different and even more fascinating story to the telling of which the remaining chapters must now be devoted.

34

'TWIXT SEA AND LAND

HITHERTO our attention has been taken up mainly with animal life in the sea. We have seen how that wonderful, beautiful, and complex picture of life in the sea to-day was built up through the ages. We have watched type after type come in and go across the submarine stage. Some have disappeared entirely. Some have declined but have left straggling survivors behind. Others have struck out on fresh lines, evolved, and are now in the full flood of their careers. The last now dominate the stage, but in the background ancient and medieval survivors still play a part and add to the interest and wonder of the whole.

Now and then our attention has been drawn to the realm in which we ourselves live. We have caught glimpses of lowly plants entering the fresh water. We have seen how they escaped from the bondage of aquatic and semi-aquatic conditions and have prospered on dry land, and prospering have spread a carpet of verdure over the ground and beautified the scenery with stately trees. Against this lovely background this terrestrial stage became dominated by the newest and most colourful types which are displayed to greater advantage because skilfully interspersed with the more sombre ancient and medieval survivals.

Following on the trail of these first explorers of the land and feeding on their débris have come multitudes of single-celled animals, worms, and snails playing their parts in obscurity. Less obscure were the 'creepy crawly' creatures with many legs, active, agile, but still small. To these were added the scorpions and cockroaches, mites and spiders. Some of these climbed the stems of plants and, dropping into the air, learned how to fly and so introduced into that element dainty touches of movement over woodlands and pastures.

Away back in late Old Red Sandstone times a portentous event took place without noise or uproar. Some aquatic vertebrates discovered that they could move about on land and not only live, but get a living. We have already been introduced to the first pioneers, clumsy round-bodied fishes with lungs, that slithered with swimming movements across the mud flats from pool to pool, shoving themselves along mainly by their tails as though they were still in water and preventing themselves from sliding back by thrusting their stout fins into the mud. For this the fin rays were of little use and ultimately disappeared. The fleshy axis of the fin with its supporting skeleton provided just what was needed. The muscles and supporting skeleton strengthened. The end broadened, gave a better hold upon the mud, and became a foot. All this sounds quite imaginative, another piece of extrapolation, but not entirely without foundation in fact. The precise details of the structural changes which took place have not yet been revealed by fossils, but that some such changes as these took place is proved by the varied kinds of animals with legs and feet whose fossil remains are

found in the Carboniferous coal-measures of many lands. Their legs had precisely the same fundamental plan as those of all land animals including our own. Each leg consisted of three main parts. An upper part supported by one long bone attached to the body at the shoulder and the hip. A middle part supported by two long bones lying side by side. A lower part which rested upon the ground and was made up of a broad palm or

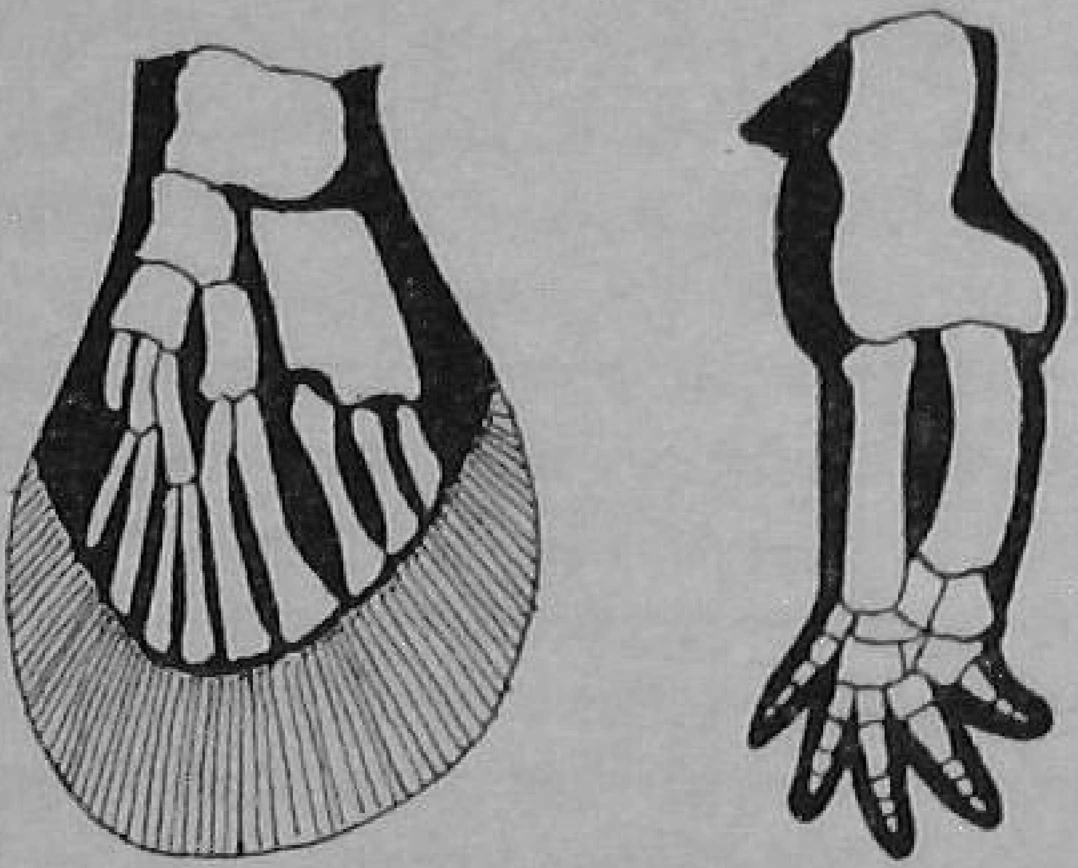


FIG. 20. THE STRUCTURE OF A FIN AND A LEG COMPARED

White = bone; black = flesh; lines = fin rays

sole with five fingers or digits and supported by many small bones.

Sundry details in these fossilized skeletons leave no doubt that they belonged to animals closely allied to frogs and newts. On this basis it is reasonable to assume that they had much in common with them also in their fleshy organs and their mode of life. They too must have had moist slimy skins derived from their piscine ancestors, without any device for preventing the rapid loss of moisture from the body when it was exposed to the air. They lived, therefore, in damp and marshy situations with easy access to fresh water. This inference is supported by the fact that so many of their remains have been found in the coal-measures.

The eggs of these animals must also have lacked protection against desiccation and so, as with the fishes and the frogs, they

were laid in water, with the result that for the early part of life they were purely aquatic animals. These inferences find interesting confirmation in the discovery of certain fossil remains found in the Lower Permian rocks of Germany. These revealed little animals only 2·5 inches long furnished with external gills like those of tadpoles. Because these creatures were, and still are, under the necessity of spending the early part of their lives in water, they are classed together as Amphibia (*amphi*= double, *bios*=life).

The earliest amphibian remains found hitherto come from the Upper Devonian rocks of Greenland – another interesting sidelight upon the climate which must then have been much warmer in that part of the world than it is now. They were quite large animals for some of their skulls are eight inches long. These give rise to small forms which lived on until Permian times and may have been the forerunners of the present-day frogs and newts.

Another race of small Amphibia, that flourished especially in the coal-measure marshes of the United States, became highly specialized in divergent directions. Some retained the normal newt-like shape; others specialized by the loss of their limbs and assumed snake-like forms.

Contemporary with these were many large types which are spoken of collectively as labyrinthodonts, a name based upon a peculiarity in the structure of their teeth. When thin slices of these are examined the enamel which covers the surface is seen to penetrate deeply into the dentine and to become folded and frilled with labyrinthine complexity.

At first many of these labyrinthodonts led a wholly aquatic life. This is inferred from the fact that in their legs the joints between the bones were cartilaginous and flimsy and unsuited for carrying the heavy weight of the bulky body. This must normally have been buoyed up in water. Their bodies were still round and fish-shaped. The tail was long and flattened from side to side, an indication that it was still used for propelling the animal through water.

In other carboniferous labyrinthodonts the limbs were much stouter and the surfaces, by which the bones were articulated

with one another, were ossified and firm. Evidently their legs were capable of carrying the whole of the weight of their stout, slightly depressed bodies. The tail was short and stumpy and evidently of little use for propelling the creature along.

These animals still flourished during the Permian. One of the most completely preserved skeletons and, therefore, most fully known came from Texas. It was *Eryops*, a big lumbering creature eight feet long. When it was not moving about it rested its belly on the ground and stuck out its knees and elbows on either side. Energized, it may be by pangs of hunger, it lifted its body clear of the ground and waddled away in search of food.

Living at the same time as *Eryops* was *Cacops*, a smaller and probably more agile animal a little less than one and a half feet long with a head much larger in proportion to the size of the body than in other Amphibia.

In Triassic times the labyrinthodonts spread far and wide over the world even as far north as Spitzbergen. The amphibia then attained their acme in size and one of them, *Mastodonsaurus* by name, had a head that was no less than three feet long. But such indications of prosperity were deceptive for many signs of degeneration in bodily structure began to appear. The limbs became small and weak. This fact, coupled with the shifting of the eyes up to the top of the head, as in the crocodile and hippopotamus, show that they were abandoning the dry land and were resuming once more a predominantly aquatic mode of life. Indeed some of the remains found in Spitzbergen show that at times they left the fresh waters behind and wandered out to sea. Before the close of the Triassic period they had disappeared. One reason for this may be found in the rise and rapid spread of new competitors, the Reptiles, a much more efficient race of true land animals.

35

FRESH FIELDS AND PASTURES NEW

FOR a vertebrate to live successfully the life of a land animal three problems must be solved. It must be able to breathe air. It must have legs that can support the whole weight of its body. Finally, its body must be effectively protected against excessive loss of moisture from its surface.

The first of these was already solved in their early ancestors among the Devonian fishes. The second condition was fully attained during Carboniferous times by a number of Amphibia. In Permo-Carboniferous times definite progress had been made towards a solution of the third problem by a few animals which therefore passed beyond the amphibian stage and became reptiles.

Before dealing with the geological history of this highly interesting group of animals it will be useful to glance at the way in which the third problem was solved. Here, once more, the actual evidence does not lend itself to preservation in the fossil state. We must assume, therefore, that the way in which it was solved originally in the earliest reptilian pioneers is accurrately reproduced in their descendants living today. In the first place, as many people know who have handled a lizard or a snake, the skin is not moist and slimy, like that of a frog, but is dry and shiny. When a snake 'casts its skin', what it really casts is its cuticle, a thin film which covers its skin, and which comes away as a continuous piece. In chemical make-up this is similar to the chitin which covers an insect's body and, like that, is impervious to moisture; a kind of mackintosh in reverse in that it keeps moisture in instead of out. Having cast its cuticle the animal quickly secretes a new one. Thus the precious moisture, which is so essential to the make up of blood, digestive juices, and other fluids of the body, is effectively conserved.

This device overcomes the difficulty in so far as the fully grown animal is concerned, but that is only half the problem.

The other half is how to protect the young, during the very early stages in its development, from the same loss. In the Amphibia the problem was by-passed by laying the eggs in water, which is one important reason why amphibians have always been tethered to a life spent in moist localities in the vicinity of water. A true land animal must not be bound thus. It must be free to roam everywhere and lay its eggs in any spot where it may settle down on the landscape.

Few people have seen the eggs of a snake or a lizard, but everybody is familiar with the egg of a bird, which is fundamentally the same in all salient respects. The first feature to notice is the number of eggs that are laid. In a mass of frog's spawn there may be hundreds of small eggs. In a bird's nest there may occasionally be nearly twenty, but normally only four or five. Each one of these is very much larger than each of the eggs of a frog. The advantage derived from laying so few eggs is that much more food may be stored as yolk, in each egg. The store of food in a frog's egg is so small that the animal emerges not as a little frog, but as a tadpole, a mere baby, half developed, turned out into the world to forage for itself. In the large yolk of the reptile's egg the embryo finds enough nourishment to enable it to go on developing until it is equipped with legs, lungs, and impervious skin, ready to share life fully with the grown-ups. Just at this point the birds overshoot the normal reptilian mark by making nests and caring for their young.

Around the yolk is a fluid bath, the white of egg, which serves a double purpose. It counteracts any danger arising from rapid loss of moisture by evaporation and supplies moisture for the fluids increasingly required in the growing body. Additional shields are provided by the shell and several skins. Nevertheless, these are porous and allow the air to enter and to oxygenate the blood of the embryo.

On rare occasions the eggs and impressions of the skin of reptiles have been found as fossils. These supply some evidence which shows that the account just given was true for past ages as well as for the present.

The problem of equipping animals effectively for life on dry

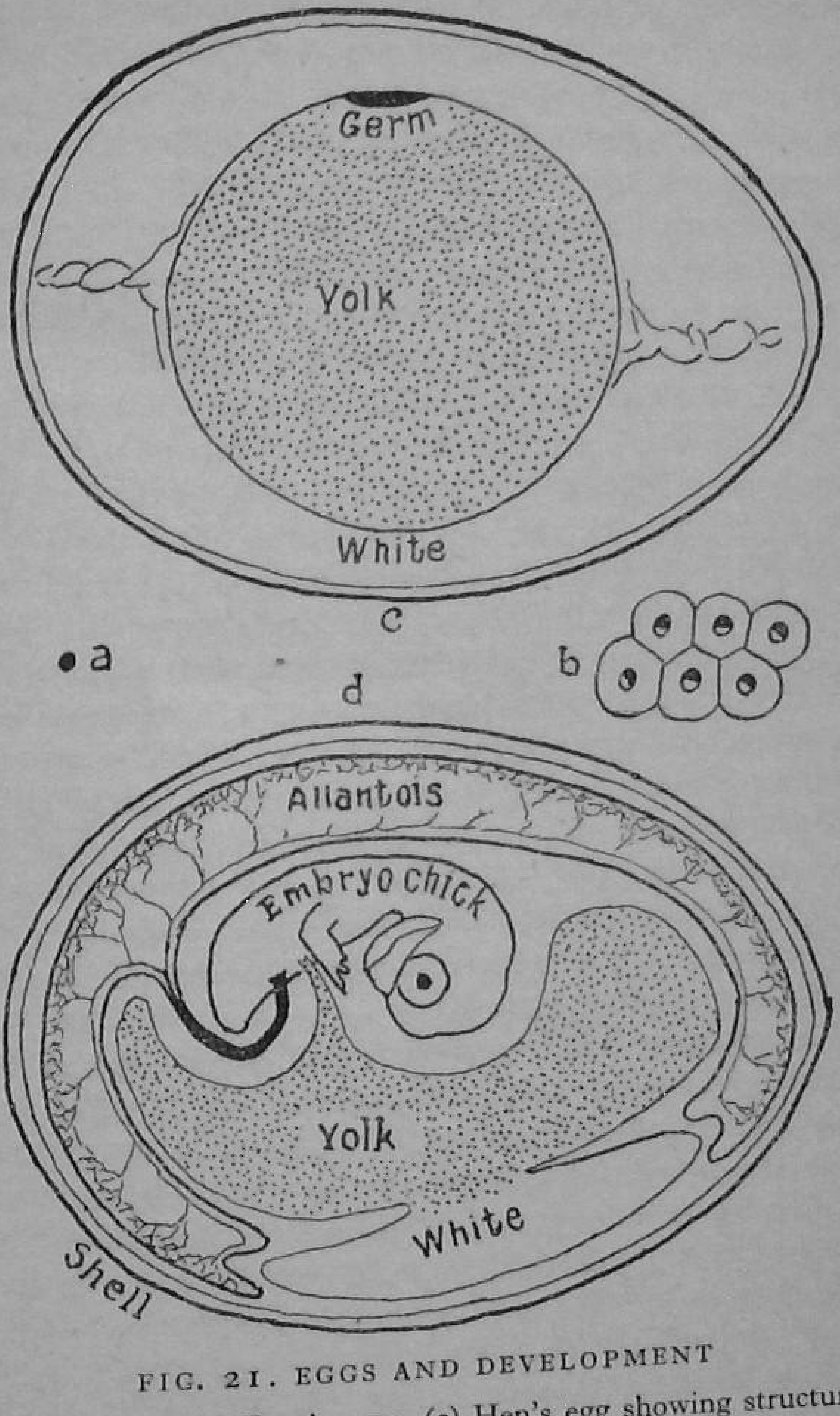


FIG. 21. EGGS AND DEVELOPMENT

(a) Cod's egg. (b) Frog's eggs. (c) Hen's egg showing structure. (d) Hen's egg at about the ninth day of incubation

land was so successfully solved that we are now confronted with the problem how to portray the results of that success in the space of a few pages. Those early pioneers on land had no

competitors. They entered into sole possession of fresh and open fields as yet unoccupied except by the much smaller insects, scorpions, spiders, and the like. They were presented with every conceivable opportunity for gaining a livelihood on land, in the water, and even in the air. Naturally, therefore, as they went up on to the land to possess it they multiplied in numbers, underwent endless adaptations, radiating out in every direction across the open territories, and occupying every habitat it offered. Such an evolutionary phenomenon is known as an Adaptive Radiation. With this preliminary sketch in mind we turn to look at the earliest known reptiles.

The First Reptiles

Almost complete skeletons of *Seymouria* have been yielded by terrestrial deposits of Lower Permian age in Texas. This little creature, only two feet long, resembles the more primitive labyrinthodonts in many respects. Indeed, the similarity is so close that it is almost as difficult to decide whether it was an amphibian or a reptile as to say whether sunset and dawn belong to day or night. This is, of course, just another way of saying that it was in a state of transition from one to the other. It had a moderately stout body, a long tail and probably fed on insects.

Contemporary with *Seymouria* were other reptiles both small and large which had blunt teeth suitable for crushing coarse food. The largest of these was *Pariasaurus*, a heavy-bodied animal which seems to have been herbivorous. The elbows and knees of its powerful legs were turned inwards closer to the sides of the body, an attitude better suited mechanically for supporting its weight. Some of its features point to a slightly earlier origin of reptiles in late Carboniferous times before they had won clear of a marshy habitat. A few fossils have been found which support this inference.

It has been noted above that in his study of fossil vertebrates the researcher is almost entirely dependent on the examination of skeletons. In dealing with these he is like an Indian, with trained eye following an animal by means of its trail. He sees

many signs that other people would never notice; a broken twig, a displaced blade of grass, a fragment of disturbed soil. For him these are full of meaning. So, likewise, one who is always handling bones catches glimpses of differences between this and that which put him on the track along which Nature has passed when producing new types. It would defeat our purpose if we burdened these pages with many of these bony details. It will, nevertheless be helpful if reference be made to a few.

The normal shape of the head in these early reptiles, like that of an amphibian, was roughly triangular in outline and flattened from above downwards. The top and sides were completely roofed over with bone, with the exception of a pair of large holes for the eyes and smaller ones for the nostrils. The brain was very small and occupied a narrow case situated under the middle line of this roof. Behind the eyes and on either side of the brain case was a space which in life housed the muscles which worked the jaws. This part of the skull is called the temporal region. In Amphibia, and the very primitive reptiles such as those just described, this had a complete covering of bone. In all other reptiles this covering was pierced on each side by one or two large holes called fossae. In some the one fossa was on the top (A). In others it was on the side behind the eye (B). In a third lot two were present, one above the other on the side (C). These three arrangements are mutually exclusive on the same principle that if a person is in one spot he cannot be in another. If an evolving line of reptiles showed condition (A), its members could not also exhibit either (B) or (C). Each arrangement is, therefore, a touchstone of affinity. That is to say all those with arrangement (A) were more closely related to one another than to any that showed either (B) or (C).

Mammal-like Reptiles

It is a remarkable fact that the majority of late Carboniferous and Permian reptiles had the temporal fossa on the side (B). Remarkable because that is precisely the condition which is shown by all mammals. In fact it was from these early mammal-like reptiles that true mammals ultimately arose.

The majority of the fossil remains of the early mammal-like reptiles come from the Permian red beds of Texas. Only a few have been found in Europe. They were all elongated, long-tailed creatures with slightly sprawling legs. Their skulls, like those of the mammals, were tending to become compressed from side to side. Though their teeth were still simple sharp cones, they varied in size. Several near the front of the jaws recall the big piercing canine teeth of the dog and tiger. One group, represented by *Dimetrodon*, had an amazingly high frill along the middle of its back supported by very tall bony spines. What was its function? No one knows! It may be an expression of sheer exuberance on the part of Nature, or it may be only one way of getting rid of superfluous lime.

Abundant remains of more advanced mammal-like reptiles have been found in the Karroo beds of South Africa which are of the Upper Permian and Triassic age. They include all the known carnivorous reptiles of the Permian and a few of the herbivorous forms. One of the best known of the former is *Cynognathus* (*cyno*=dog, *gnathus*=jaw). As this name implies, its teeth resembled those of the dog in having small but conical incisors in front, large piercing canines followed by cheek teeth with cutting edges. The teeth were, however, still reptilian in that each cheek tooth had only one fang or root. The animal was 4 to 5 feet long, quite small compared with *Geikia*, which was 14 feet long.

Dicynodon and its relatives were world-wide in their distribution. They were clumsily built animals, some of which, like the hippopotamus, lived in rivers and lakes. Except for the presence of two upper canines the jaws had lost their teeth and were covered with a sharp sheath of horn, like the jaws of a tortoise. As in this pet animal this horny jaw could be used for cropping soft vegetation. In other smaller reptiles the cheek teeth had surfaces adapted for grinding drier vegetable food.

In all these reptiles the lower jaws articulated with a moderately firmly fixed bone called the quadrate. In mammals this bone is very small and takes no part in this articulation. In these later mammal-like reptiles the various stages leading up to the disappearance of the quadrate from the articulation and

the transference of its function to another bone are seen. Towards the close of the Trias this important branch of the reptilian stock was almost wiped out, but somewhere on the landscape diminutive representatives found a haven of refuge, possibly in the trees, within which the final transition to the ranks of the mammals was accomplished. There we must leave them for a while.

Other Land Reptiles

The remaining groups of Permian and Triassic reptiles, though not so numerous as those just considered, were still more varied in their adaptive modifications. *Rhynchosaurus* was like a lizard about 2 feet long. In its temporal region it had two fossae (condition C). Skeletons found in the British Trias show that it was almost identical with the New Zealand lizard *Sphenodon* which was discovered when Captain Cook first visited those islands. This lizard was then common everywhere. It is said that when pigs were introduced into New Zealand some ran wild and, not being fastidious about their diet, they ate these lizards freely and brought them to the verge of extinction. When, however, it was realized that *Sphenodon* was a 'living fossil' of great scientific interest which had survived with very little change from Triassic times, measures were passed to secure its protection and a sanctuary was provided in one of the smaller islands.

Another group of Triassic reptiles with similar temporal fossae adopted a semi-aquatic mode of life like that of the crocodile. In fact it gave rise to a long line of descendants that culminated in the alligators and crocodiles of tropical rivers to-day. During the Jurassic one branch from this line abandoned the habit of coming on to the land and launched out into the deep. Its legs became paddles and its tail developed a fin, and it changed into a perfect free-swimming marine reptile.

Another similarly long-ranged type is represented by the tortoises, snappers, and turtles which occupy land, rivers, and sea respectively. The complete covering over the temporal region of the skull points to descent from very primitive reptiles,

but very little is known about the early stages in their evolution. By Triassic times they had settled alongside rivers and adopted an amphibious habit. During the Jurassic some moved into habitats along the shore and a few started off on a free-swimming career in the open sea. One of these, *Archelon*, living in Cretaceous times, was 12 feet long.

On the other hand in early Tertiary times some abandoned the riversides and ventured forth into the open landscape which at about the same time became covered with grass. Protected by their rigid bony armour they flourished and grew to a greater size even than the giant tortoises of the Galapagos Islands. *Miolania*, from the Pleistocene of Australia, had a skull 2 feet broad.

The Dinosaurs

Turning now from these slowly changing long-ranged types, which had their roots in the far-distant past and their twigs in the present, we encounter others which evolved rapidly, became for a while highly successful Lords of Creation, then declined swiftly and died out, leaving no representative to-day to show us exactly what they were like. Such were the *Dinosaurs* that in Triassic time competed with the mammal-like reptiles and won. Little is known of their early ancestors, but that little indicates that they descended from the same stock as did the crocodiles. At a very early stage they abandoned the habit of walking on all fours and, rising up on their hind-legs, adopted a bipedal gait. This change threw all the weight of the body on to the hips. In response to this the hip-bones elongated and united with a long stretch of the backbone. This condition is familiar to any one who has carved a chicken or a turkey. These fowls are also bipedal and their large hip-bones occupy much of their backs. With the hip-joint as the fulcrum the body in front was balanced by the long stout tail behind. The hind-legs became much larger than the front ones. They increased in length by the elongation of the thigh- and shank-bones and to a less extent by lifting the sole of the foot off the ground and walking on their toes. Many of them were swift runners and

could leap along like a kangaroo. Half of them were carnivores and their jaws were armed with numerous sharp-pointed teeth. They exhibited a great range in size. At one extreme was *Compsognathus*, no larger than a cat and just as active. At the other extreme was *Tyrannosaurus* whose remains have been found in the Cretaceous rocks of North America. It stood 19 feet high on its bare feet and was 47 feet long from the tip of its snout to the end of its tail. It was the largest flesh-eating animal known throughout the long history of this world. It is inconceivable that this brute could have been very agile in the pursuit of its prey. There was, however, no need for it to be so for clumsy vegetable-feeding dinosaurs were at hand ready for it to prey upon and find ample food for the support of its huge frame.

These herbivorous dinosaurs made up the other half of the community. Their cheek teeth, like those of present-day cattle, had deep crowns and broad grinding surfaces. Sometimes the front teeth were replaced by a sharp-edged horny covering on the jaw, similar to that seen in a tortoise. This was the case in *Iguanodon*, which was the first dinosaur of which complete skeletal remains were found.

In both types the front legs, though small, were useful for holding food while they were feeding. Some strains of carnivores changed over to a vegetable diet and, in common with some of the other herbivores, reverted to the habit of walking on all fours. The digestive organs of vegetable-eaters are more bulky than those of flesh-eaters and naturally their bodies became correspondingly cumbersome. This may have been one of the reasons for this reversion. On the other hand they were subject to the attacks of increasingly more fearsome carnivores, and they resorted to various devices for defence. In *Triceratops* the skull was very large and furnished with long sharp horns and with a shield-like rampart of bone which rose at the back of the head. In *Stegosaurus* a frightening frill of large vertical bony plates developed along the middle of the back. Its tail carried a number of long spines which provided a useful, if subsidiary, means of defence. All these extra loads added to the weight of the body and may also have stimulated

the return to the primitive four-footed gait. It may be, of course, that this excessive formation of bone was another example of the physiological loss of control over the absorption and secretion of lime. Even so Nature seems to have put the additional encumbrance to good use.

Some of these herbivores attained dimensions exceeding that of any other known land animal that has ever existed, rivalled only by some of the largest of living whales. It seems impossible that such bulky bodies, twenty or more tons in weight, could have been supported even by the pillar-like legs they possessed. A solution to the problem is indicated by sundry details in the skeleton. The joints of the legs were all loose, and the articular surfaces of the bones were covered with cartilage. This points to a life spent with the body mainly submerged in water. The fact that the eyes and nostrils were close to one another on the topmost point of the head shows that even when completely submerged the animal raised these just above the surface and was able both to see and breathe.

During Jurassic and Cretaceous times this great race of animals dominated the land the world over, but at the close passed away completely.

Aquatic Reptiles

The reader must have noticed previously that occasional members of different stocks resorted to the water for a livelihood. There were, however, two stocks of which all known members were aquatic. They are represented by *Plesiosaurus* and *Ichthyosaurus* respectively. These were the tyrants of the sea throughout Mesozoic times. The former, like the modern seal, was not perfectly at home in the sea, but returned to the beaches to bask in the sunshine and breed. The best description of it was that given by T. H. Huxley long ago, who said it was like a turtle with a snake threaded through it. As with the turtle its legs were converted into paddles and were its chief organ of propulsion. The ichthyosaurs were represented in Permo-Carboniferous times by a small animal, *Mesosaurus*, with a length of 3 feet, of which half was made up of tail. This

was flattened from side to side and was evidently a strong swimming organ. The limbs, however, still had the structure and size of walking legs. Evidently the creature had, geologically speaking, only recently adopted the aquatic mode of life. In Triassic times true ichthyosaurs already existed fully equipped in every way, apart from breathing, for that mode of life. Their bodies were as streamlined as those of the fishes. Fossilized impressions of the body itself show that they had fins on both the back and the tail. Their legs were shortened and converted into paddles. In rare examples the fossil remains of embryos have been found within the skeleton, a fact which shows that instead of laying eggs they gave birth to their young alive. The need for returning to the beaches as did the plesiosaurs was thus obviated.

Reference should be made to *Mosasaurus* which entered into successful competition with the ichthyosaurs in the Cretaceous seas. It was akin to the present-day Nile lizard but was 25 feet long and much more perfectly modified for a life spent wholly in the sea.

Flying Reptiles

From all that has been said above we get a very different impression of the reptiles as a whole than that produced by a visit to the reptile house at a Zoo. In their prime, during Mesozoic times, they were amazingly virile and adaptable. One more example of this now comes up for consideration. In addition to conquering the land and dominating the sea they invaded the air.

Human attempts at doing the same have centred round the balloon which is lighter than air and the parachute which is heavier. The one starts from the ground and rises. The other starts from a height and drops slowly. How the rate of falling is slowed down may be illustrated by a simple experiment with two pieces of paper of the same size. Both are heavier than air. Crumple up one piece into a ball. Drop both from the same height. The ball will descend rapidly, the uncrumpled sheet slowly. In the former the surface of the ball is small in

proportion to its weight. In the latter it is large, and offers a correspondingly greater resistance to the air as it falls. It therefore drops more slowly.

The reptiles, like the insects, solved the problem by adopting the parachute principle. No fossils have been found yet that record the early stages in their triumph, but at the opening of the Jurassic animals existed that were already equipped with a thin extensive fold of skin which could be held stretched out from the side of the body. This was supported by the arms and by an enormously elongated and strong fourth finger, twice as long as the arm itself. The first three fingers and all the toes were armed with strong claws by which the animal could scramble up cliffs and trees, and dangle from ledges and branches. Thence it dropped into the air and, spreading its 'wings', could make use of the wind and of ascending currents of air for soaring and gliding. The head was very large and being supported by a framework of slender bones, was consequently very light. The mouth was large, armed with long sharp teeth, and, therefore, well adapted for catching insects on the wing. These early flying reptiles had long lizard-like tails, but in the later Jurassic types these were short and stumpy. These pterodactyls attained their fullest development in Cretaceous times. The smallest were about the size of a sparrow, but at the close of their career there were giants which had a spread of wing equal to 25 feet.

Meanwhile reptiles closely linked with the dinosaurs made a slightly different, but in the end a highly successful, attempt at flying. The requisite extension of area was attained, not by a fold of skin, but by the evolution of feathers.

The earliest fossil remains of a feather-bearing animal were found in the Lithographic limestone from the Upper Jurassic of Germany. It was *Archaeopteryx*. This was about the size of a pigeon and had affinities with the small bipedal leaping dinosaurs. It had a long, thin tail fringed with feathers on either side. Feathers were similarly arranged along the back of the arm and third finger. Its feet were like those of a perching bird. It had, therefore, a great advantage over the pterodactyls in that after flying it could easily alight on and grasp the bough of the

tree in which it lived. With stout claws on fingers and toes it could also scramble along and up the trunk and branches. The wide expanse of feathers on tail and arm enabled it to launch into the air and glide across the open spaces from tree to tree.

Evolution from this type of feathered creature progressed so rapidly that by Upper Cretaceous times perfect birds had come into being. Only the fossil remains of sea birds have hitherto been found, though no doubt they abounded inland also. One of them, *Ichthyornis* by name, had powerful wings and was a strong flier. Another, *Hesperornis*, was a weak flier but a perfect diver. All the early true birds, along with *Archaeopteryx*, had teeth. During the Tertiary these disappeared and were replaced by a horny beak.

Such successful fliers easily escaped from disasters which overwhelmed and buried normal land vertebrates. Consequently, their fossil remains are rare. Nevertheless we have only to look round and listen to realize that to-day birds are in the full flood of their career. Just as some of the reptiles, in their heyday, returned to the sea whence their ancestors came, so some of the birds ceased to fly and returned to a life spent on the ground. This was particularly the case in New Zealand where it was safe for them to do so because of the complete absence of small carnivores like stoats and weasels. The kiwi is perhaps the most intriguing example. It is the diminutive survivor of a giant race of flightless birds, the moas, some of which were 10 or 11 feet high. Emus, ostriches, rheas are other examples living to-day in various parts of the southern hemisphere.

Part Six: The Coming of Man

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MAN'S FRIENDS AND COMPANIONS

A FUNDAMENTAL factor in the successful reptilian invasion of the land was the provision, by the parent, of a generous supply of food for the nourishment of the young during development within the egg. This enabled it, before hatching, to attain a stage at which it was fully equipped with lungs and legs for immediate use in its life upon land. There being no competitors to contend with, the first reptiles found this equipment sufficient as a basis for securing success in all the walks of life in this new sphere. The smallness of the brain and the simplicity of its structure implies that their senses were dull and their reactions slow, and that, generally speaking, they lived at a walking pace. Birds provide an interesting exception for, though their early development still took place in the egg, the young were cared for by the parent after they hatched out. This gave further time for the growth of the brain which is larger in them than in normal reptiles.

The lowliest mammals alive to-day are the duck-mole and spiny anteater of Australasia. They still lay eggs but, for some time after hatching, they nurse their young. Unlike the birds that feed their young with raw food collected from the landscape, these mammals feed them with milk secreted from glands in the mother's breast. Similar mammary glands characterize all the other animals which succeeded the reptiles. For this reason they are called Mammals.

In all other mammals the egg is not laid but is retained within the parent's body. This secures for the embryo uniform conditions of warmth and moisture as well as additional safety

from foes. During development a part of the body of the embryo is brought into such close and intimate contact with the adjacent part of the parent's body that the blood vessels of the two lie alongside one another. This arrangement is called a placenta, and by its means the blood of the embryo is supplied with nourishment and oxygen. As the embryo grows the placenta grows also so that, unlike the egg which yields only a diminishing supply of food, the placenta provides an increasing supply in response to the growing need. Development can, therefore, be carried on for a still longer time.

FIG. 22.
AN EMBRYO RABBIT NINE DAYS BEFORE BIRTH

Note the large size of the brain in proportion to that of the body (after Marshall)

The brain and nervous system are so vital to the sensitiveness and responsive agility of a mammal during life that before birth they outpace the mere mechanical organs of the body in rate of growth. At birth or a little later the animal is, therefore, able to exercise a fuller and more efficient control of its movements and other functions. Another important but, perhaps, less vital feature about mammals is that the body is covered with fur. This serves a double purpose. It slows down the rate of loss of heat and moisture from the body so that mammals, unlike reptiles, are warm-blooded animals.

These changes and the triumph they inaugurated did not come all at once. As seen above, their reptilian ancestors flourished and were then beaten almost to extinction in Triassic times or immediately afterwards. Eighty million years then passed before the opening of Tertiary times when mammals became supreme. Meanwhile tiny descendants of the mammal-like reptiles lived in obscurity, probably in the trees, and fed on insects.

The oldest fossil that may reasonably be regarded as that of a mammal is *Tritylodon* from the Upper Trias of South Africa. It is unfortunately very imperfect, for only the snout and the front part of the brain case are preserved. This fragment is only

one inch in length so that the animal was no larger than a little rabbit. It was undoubtedly a vegetable feeder, for its cheek teeth had flat square crowns armed with many small blunt tubercles. Remains of closely allied forms have been found occasionally in the Upper Jurassic, but in Cretaceous and early Tertiary rocks they are more common and show that the animals were larger. Evidently this type of mammal had some degree of success in competition with its reptilian rivals, but the further history of this type is still an unsolved problem.

Jaws and teeth of a very different pattern have been found in the Jurassic rocks of England and North America. Their original owners were no larger than an ordinary rat. In common with mammals generally the teeth, in different parts of the jaw, were modified to serve slightly different functions. Those in front, called incisors, were for nibbling. Behind them were the piercing canines. In the cheek the teeth were molars or grinders. They were fixed in the jaw by two or more roots and their crowns were armed with three sharply pointed cusps, like those in the hedgehog and mole which feed on insects, worms, and slugs. Little more than this is known about these Jurassic forerunners of all later mammals. Unfortunately no fossilized remains have been found to give precise pictures of the changes which these animals and their descendants underwent during the next 50 million years, but from the end of the Cretaceous onwards the fossil evidence is copious. The mammals, which do not lay eggs but bring forth their young alive, are divided into two divisions of which the smaller and more primitive includes the pouched mammals or marsupials. Especial interest attaches to one group of these represented by the opossums which range at the present throughout the American continent. In late Cretaceous times a closely similar little animal was already in being in North America, and during the early Tertiary spread far and wide over the world. Like some of its descendants today it lived in the trees. In this and many other respects it presents us with a living picture of the ancestral stock from which descended not only the marsupials, but possibly all other mammals including Man.

Before the full stream of evolution of the higher mammals set in, the continent of Australia was separated by sea from the rest of the world. Here then the marsupials, shielded from more advanced competitors, evolved independently into that curious fauna which now characterizes that continent. This includes herbivores and carnivores, swift runners and leapers, climbers and even gliders. In many of them the placenta is still not perfected and consequently the young are born immaturely developed. They are then carried by the parent in a pouch – the marsupium – and are fed with milk until they are able to take care of themselves.

In the other much larger division of the Mammalia, called the Placentalia, the young are more fully developed before they are born. Having this advantage they outstripped and largely ousted the marsupials from the northern hemisphere and Africa. Though they have passed their heyday, they are still astonishingly varied and numerous.

Comparatively few people have seen many of these mammals in their natural haunts. Fortunately most large towns and cities have museums and some zoological gardens where their beauty of form and wonderful adaptation to different modes of life may be seen illustrated. Apart from these, dogs, cats, cattle, horses, and a few others are familiar to all and furnish examples of some of the most striking of these modifications.

Before setting out to trace the story of the higher mammals we must pause to glance at the ways in which the evidence upon which that story rests has been preserved. It has been seen earlier that for animals living in the sea, conditions for the preservation of their shells and bones are very favourable. Over the haunts where they live and die sea currents are perpetually shedding showers of sand and mud which rapidly cover their remains and preserve them from destruction. For those that live on the land the conditions are quite different. When an animal dies its carcase usually lies on the ground. Its flesh is eaten by scavengers or destroyed by bacteria. Even its bones are dissolved by the rain and pulverized by frost. It is only exceptionally that the animal sinks in a bog and is engulfed in peat. Only occasionally is it caught in a flood and carried into

a lake or into the sea. Even so it rarely sinks as a whole, but falls to pieces as it rots and its bones are scattered. This latter was the mode of preservation of those mammalian remains which were discovered during the eighteenth century in the Tertiary rocks of the south-east of England and in the centre of France. Since then these fossils have been systematically collected and described.

In the western states of North America much more favourable conditions prevailed. In connexion with the great earth movements that took place at the close of the Cretaceous and the opening of the Tertiary, crescentic ranges of mountains were crumpled up and were placed so that the horns of their crescents pointed west and enclosed extensive basin-like hollows. No sooner were the mountains uplifted than atmospheric agencies began to wear them down and rivers carried the débris into the basins or spread it out over the plains to the east. Under these circumstances it is not surprising that, while many skeletons were no doubt left exposed and were utterly destroyed, a goodly number were buried and preserved. In the middle nineteenth century such enterprising American pioneers as Leidy and Cope ventured out into the wilds, as they were then, not to found settlements but to collect fossils and widen the boundaries of human knowledge. They were rewarded by the discovery of rocks in these basins that were rich with mammalian remains. Similarly formed fossiliferous deposits have since been found in South America, North Africa, northern India and Mongolia and have been explored by kindred spirits.

Vast areas of the earth are as yet unexplored, and the solutions to many problems still lie hidden. Enough progress has, however, been made to make possible the unrolling of a film strip showing in broad outline the history of the Mammalia. The first picture represents the passage from Cretaceous to Tertiary times. It is a rather scrappy picture, but even those scraps are illuminating. One is the last descendant of *Tritylodon* and its relatives, the oldest true mammals. It, therefore, gives a very archaic touch to the scene. A slightly less archaic touch is given by survivors of the more numerous insect-eaters

of Cretaceous times. These little animals were like the hedgehog but without its prickles. They had sharp teeth and pointed snouts, and scurried about with their feet planted flat on the ground. A new touch is introduced by the presence of *Oxyclaenus*, a slim and still small animal that gives us a glimpse of that group of mammals that were changing their diet from insects to flesh. This was one of the forerunners of that great virile succession of races that ultimately produced the wolves, the tigers, and the lions, also the dog and the cat.

Alongside these are seen vegetable-feeders whose presence leads us to glance at the adjoining part of the strip which corresponds to the first period of the Tertiary called the Eocene. Here is seen *Hyopsodus*, a small tree-dweller which was so mixed in its bodily features that some say it is an insectivore; others, it is a lemur or primeval monkey; others, again, say it is a herbivore. Evidently, like *Oxyclaenus*, it was one of those creatures that was betwixt and between several worlds and gives us a peep at a transitional stage from one to another. About *Phenacodus* there is no such doubt; it was a genuine herbivore. It was slightly larger than a sheep with a moderately slim body and slender legs. The ends of its limb bones were round so that its joints were loose and flimsy. This feature, together with five toes on each foot, was more suited for ambling over the soft springy soil of a woodland than over more open and harder ground. Each toe was tipped with a small hoof. When first discovered it created great interest because it was believed to be the far-back ancestor of the horse. Later discoveries showed, however, that these loose-limbed herbivores died out at the end of the Eocene and left no descendants.

From all this it will be realized that at the beginning of Tertiary times the picture was a complex of very ancient, moderately ancient, and new types living together. Passing up through the later periods the pictures become too crowded and complicated for each to be dealt with separately as a whole. It will be better, therefore, to take the several strands in the early scenes and follow up the lines of evolution that they foreshadow.

The insectivore strand need not detain us long. It represents a conservative stock that underwent very little change and is with us still in the hedgehog and mole. Its survival may in part be due to a diet that, so to speak, offered no great temptation either in quality or quantity to mammals that were increasing in size. Within this limitation these aristocratic little creatures occupied habitats that likewise could not tempt larger animals. The mole, for instance, became marvellously adapted for hunting worms in their own homeland.

Cats and Dogs

Some insectivores, as already seen, became larger and fed on other four-footed animals. Since these carnivores depended for their living upon quick, often springing, movements they never became very large or bulky. On the contrary their bodies remained small and slim and their legs light. A number of the parts of the body underwent adaptive changes such, for example, as the development of sharp claws. Since the teeth were more responsive than other parts of the skeleton they have received a lion's share of attention from students of evolution.

In order to see the adaptive changes of teeth in a general setting we may recall the main changes they had undergone in previous ages. In Amphibia, as in fishes, the teeth were numerous and very small. In reptiles they were less numerous and the individual teeth were larger, as for example in the crocodile. They still remained sharply conical. In mammal-like reptiles they were beginning to become arranged in groups – incisors, canines, cheek teeth. In some of the last-named the crowns carried three sharp cusps. Among mammals the marsupials had as many as five incisors which, however, were no longer conical but had chisel-like edges for nibbling. The number of cheek teeth had settled down to the normal number of seven. The three back teeth, called molars, lying near to the angle of the jaw, were best placed for doing the hardest work whether in slicing, grinding, or pounding food. It is not surprising, therefore, that these have proved to be most sensitive to adaptive

needs and delicately reflect evolutionary trends. For this reason they are very profitable organs for study. In this rapid summary an evolutionary principle previously mentioned is well illustrated. It is that evolution often proceeds by reducing the number of parts and specializing with those that remain.

During the Eocene period the flesh-feeders multiplied rapidly and were very successful. Among them there was, as it were, a vigorous competition between the molars as to which was best placed for being the most efficient flesh-cutter or carnassial. This name is given to a type of tooth in which two or three

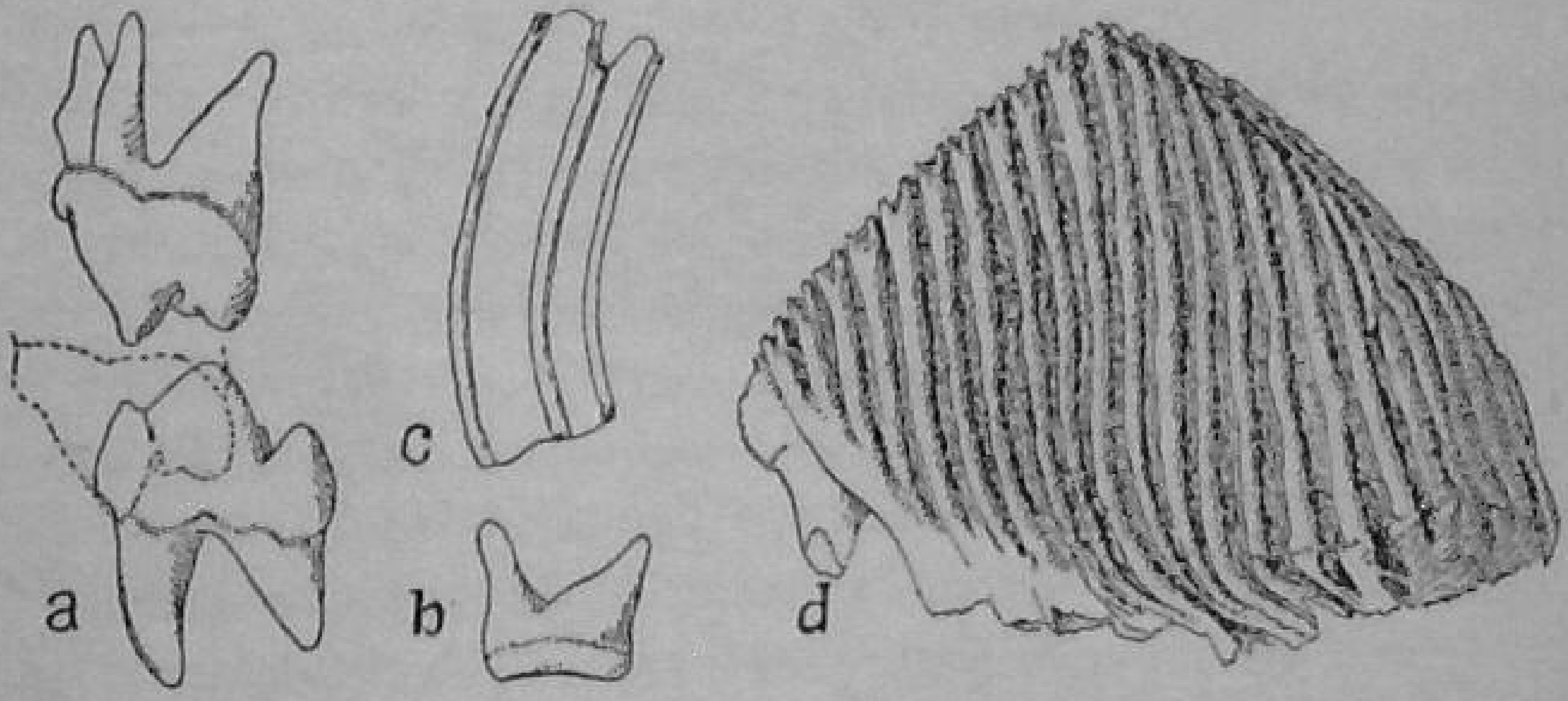

FIG. 23. TYPES OF MAMMALIAN TEETH

(a) carnassials of the dog, upper and lower. The dotted lines shows the position of the upper when the mouth is closed. Molars of (b) *Eohippus*; (c) horse; (d) mammoth

cusps have developed into long cutting edges. In the act of biting edges of the upper and lower carnassials pass one another like the blades of a pair of scissors, and can slice off lumps of flesh from a carcase.

At first the majority of the early carnivores, or creodonts, were like *Oxyclaena*, which had no carnassials but only molars suited for crushing food. About the time of the opening of the Eocene three distinct types arose. In one, represented by *Hyaenodon*, the second upper and the third lower molars became carnassials. In *Oxyaena* and its allies the choice fell on the first upper and the second lower. In *Miacis* it fell on the last upper premolar and the first lower molar. The competition lay,

therefore, between these three positions at slightly different distances from the angle of the jaw. The third and most distant position, which coincided roughly with the middle of the jaw, prevailed. It so happened that in *Miacis* the brain was a little larger than in the other creodonts. The oxyclaenid and oxyaenid types became extinct at the end of the Eocene and the *Hyaenodon* type at the close of the Oligocene. Meanwhile the *Miacis* type flourished and produced a stock from which all the present carnivores arose during Oligocene and Miocene times. In pursuit of their herbivorous victims they spread out from the woodlands into the open landscape during the Miocene. The dogs branched off from this stock at the close of this period. They underwent comparatively little change in their bodies but, judging by their present habits, evolved in the direction of social cooperation and hunted in packs like wolves. From them other new types were given off including the bears which reverted to an omnivorous diet.

The cats also arose from this *Miacis* stock towards the close of the Miocene. They walked by themselves and their bodies became highly specialized. They were perfect carnivores, silent, swift, and agile in their movements. Even their claws, when not in use, were withdrawn back on to the paw lest, striking a stone, they should make a sound. In the mouth those teeth that were little used were discarded or reduced in size, but the carnassials and canines were highly developed. Indeed in Pliocene and Pleistocene times, when many of the large herbivores developed thick skins, the sabre-toothed tigers arose. In them the canines became like long daggers having sharp cutting edges with which they could not only stab deeply but slit open the toughest hide.

Horses

The vegetable-feeders to-day fall into two large populous categories typified by the horse with its single hoofs and the cow with its cloven hoof. Because of these hoofs they are called the ungulates, and the two groups may be referred to as the odd-toed and the even-toed ungulates respectively.

The odd-toed ungulates seem to appear suddenly at the

opening of the Eocene and were represented by *Hyracotherium* in Western Europe and by *Eohippus* in North America. They were larger than a hare and were just as dainty and swift in their movements. They seem to appear suddenly upon the scene, for no trace of any ancestral type has been found in the earlier rocks of either region. The fact that they appeared simultaneously in Europe and in North America suggests that they had been evolving elsewhere, possibly in Northern Asia, and had migrated thence. In all work of this kind it is necessary to remember that there are still extensive regions of the earth's surface that as yet have not been explored by fossil hunters.

Fortunately these early migrants found favourable surroundings in North America and gave rise to a remarkable series of descendants whose remains have been unearthed from the Tertiary rocks of various ages. The evolutionary phases passed through by these are most clearly reflected in their teeth and feet. During the Eocene and Oligocene they lived in forest conditions and browsed on soft vegetation. In *Eohippus* the crown of a typical cheek tooth was square and carried blunt cusps which later elongated into short ridges and thus improved their effectiveness for pounding food. Its front feet had four toes, and the hind, three. When the feet were placed with the tips of their toes upon the ground these splayed out sufficiently to counteract any tendency to sink into the soft soil.

During Miocene times, while some continued to haunt the shrinking woodlands, the rest spread out on to the open grassy plains where the food was drier and had to be reduced by grinding. In doing this work the crowns of the teeth were worn down. This disadvantage was overcome by a progressive increase in height of the ridge-like cusps and a deepening of the valleys between. These were then filled with cement. In this way a tall type of tooth evolved made up of vertical sheets or columns of cement, enamel, and dentine. As these three constituents differed slightly in hardness, the grinding surface did not become smooth but was slightly corrugated. It was, therefore, better suited for its purpose while the increased height prolonged its period of usefulness.

But these animals did not have the grassy plains all to

themselves for the carnivores followed them there also. Having no weapons of defence these herbivores resorted to fleetness of foot as their main way of escape from destruction. This was acquired chiefly by increasing length of limb, for which purpose

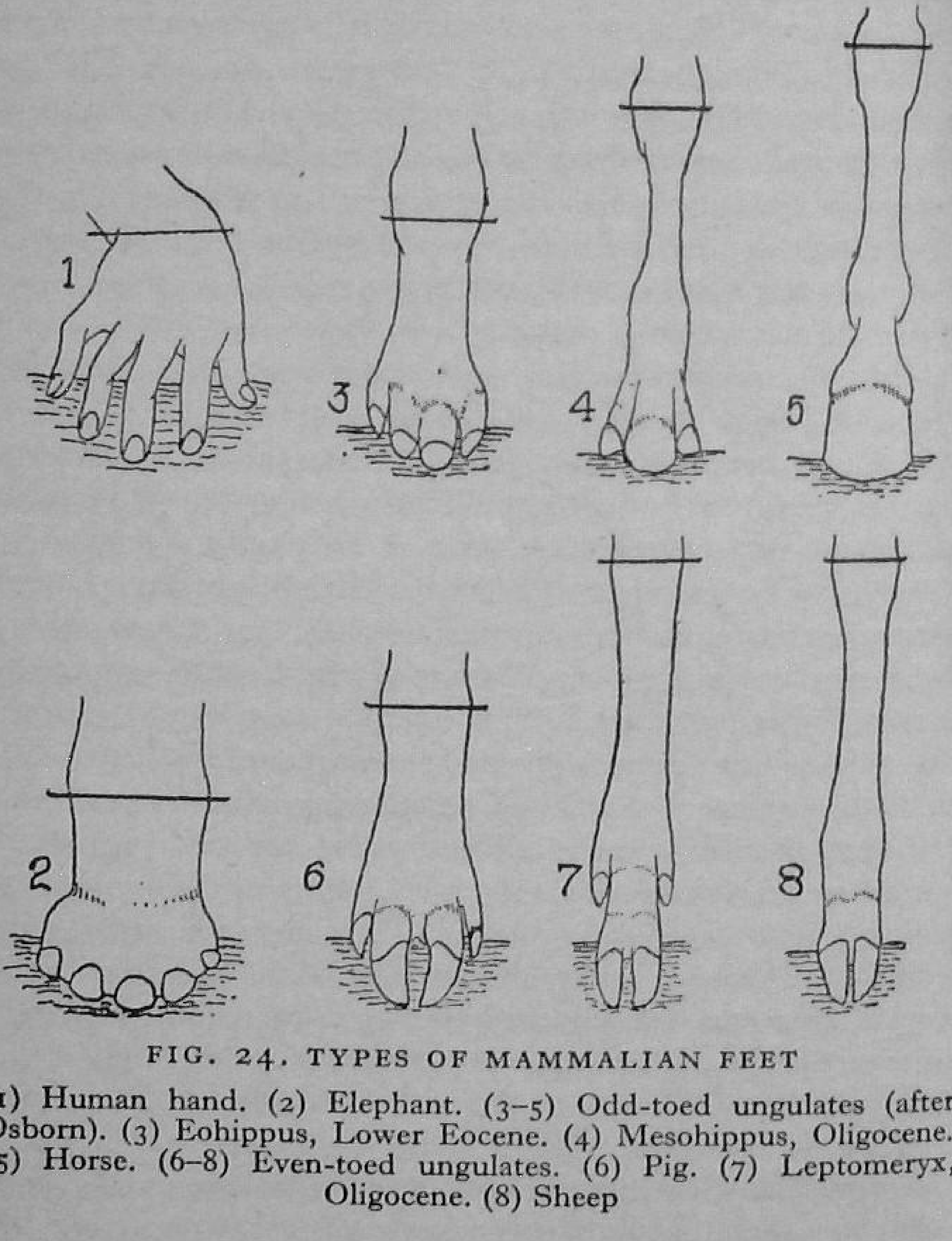

FIG. 24. TYPES OF MAMMALIAN FEET

(1) Human hand. (2) Elephant. (3–5) Odd-toed ungulates (after Osborn). (3) Eohippus, Lower Eocene. (4) Mesohippus, Oligocene. (5) Horse. (6–8) Even-toed ungulates. (6) Pig. (7) Leptomeryx, Oligocene. (8) Sheep

the soles and even the toes were pressed into service. In the horse the middle and longest toe was lifted off the ground gradually until only its tip, which was enclosed in a hoof, rested on the ground. As this toe increased in thickness and

supporting power the side toes declined and almost completely disappeared. Such was the condition attained in the late Miocene by *Merychippus*, the probable ancestor of the modern horse. These early horses spread over most of the world. It is an extraordinary fact, and one as yet unexplained, that in America, its ancestral home, the horse disappeared completely at the end of the Pleistocene. It could not have been that the general conditions had ceased to be favourable, for a few thousand years later when Europeans reintroduced the horse it multiplied freely and in three centuries spread all over the continent. It may be that some virulent epidemic disease wiped them out; but there is no evidence for this.

Pigs, Sheep, and Cattle

Pigs and sheep are typical examples of even-toed ungulates and in a general way illustrate the opposite extremes of ungulate evolution. Both animals walk upon their toes, which is another way of saying that the sole of the foot is lifted off the ground and its length added to that of the leg. In the pig the foot is in a relatively primitive state. It has four toes: two large ones in the middle carrying the 'cloven hoof', and two little side ones behind. The four corresponding sole bones are all separate from one another. The whole foot is loosely built and is well suited for walking or running on the soft soil of the woodlands, which are still its native haunt when in the wild state. In the sheep there are only two toes, for the small side ones have disappeared. The two corresponding sole bones have fused into one called the cannon bone. This is an adaptation for withstanding the sharp impact of the hoofs when the creature is running rapidly over the hard ground of the open country.

The teeth of the pig are all short-crowned, carrying blunt cusps, and are quite adequate for dealing with the soft vegetation on which it feeds. In the sheep the teeth are modified in a similar manner to that already described for the horses and for the same reason.

When in Eocene times the odd-toed ungulates were

approaching their heyday and dominated the landscape, the even-toed ungulates were in their time of obscurity and were represented by *Homacodon*, a little animal no larger than a rabbit. It was closely allied to the common ancestor of all modern types of mammals, but its feet were even-toed with two large and two small toes, similar to but more elegant than that of the pig.

From some such primitive type as this a wide diversity of creatures arose so quickly that in Oligocene times the even-toed ungulates rivalled the odd-toed and subsequently out-distanced them. Some of these, such as *Entelodon*, a giant boar with slim two-toed legs, became extinct; others, like *Gelocus*, have survived until the present with but slight modification in the tiny mouse deer and water chevrotain of southern Asia. From these also arose the ancestors of the deer and cattle. The deer remained and flourished in the temperate woodlands. Their most striking characteristic is the antler, a branching bony structure which grows out from the forehead in spring and is shed later in the year. In early Miocene times the antler was small and bore only two points or tines. Later it evolved three tines and in the latter half of the Pliocene the number increased to as many as ten or a dozen. All these stages in the evolution of the antler are repeated during the lifetime of the deer to-day. In its first pair of antlers there are only two tines; in the second, three; and so on, with each new pair of antlers an extra tine appears. The *Muntjac* of south-eastern Asia with its two-tined antler is a present-day survival of the earliest race of deer. The brief study of antlers illustrates the three main lines of evidence upon which the student of living things reconstructs the evolutionary stories: fossils, the development of individuals, and the comparison of living types.

In cattle similar bony outgrowths from the forehead appear but are not shed. On the contrary they remain, grow throughout life, and become covered with horn. In Upper Miocene times two horns were placed close together as in modern antelopes and sheep. In Pliocene times the forehead broadened and the horns became widely separated from one another, thus giving rise to the condition found in oxen.

Camels and Elephants

These tropical friends and companions are also ungulates. The camel belongs to the even-toed stock. As early as the Upper Eocene another small four-toed mammal appeared, *Protylopus* by name, which became gradually transformed into the camel by a number of bodily changes including modifications of teeth and legs similar to those already described for other even-toed ungulates. Unlike the cattle this stock, though long lived, did not give rise to a great variety of forms.

Among man's friends none look so strange as the elephant. The early phases of its evolution were passed through in North Africa where the bones of its ancestors have been found hidden in a succession of deposits in the Fayum area. These were laid down by the waters of the Nile as it developed from being an estuary to being a river. The earliest known member of this race, *Moeritherium*, appeared during the late Eocene. It was about the size of a pig. It already had a bulky body, stout legs, and normally shaped head. As it grew in size and stature the neck remained short, but the front part of the jaws began to elongate. The incisors projected forwards and could be used for digging up roots and tussocks of grass. These were pushed into the mouth by means of the flexible end of the nose which had grown in length with the jaws. Because it had four of these tusk-like incisors, two in the lower and two in the upper jaws, this stage in the evolution of elephants is called *Tetrabelodon*. This race of animals now migrated from Africa, by way of Europe, into Asia. In Middle Miocene it entered North America through Alaska. Meanwhile the two jaws shortened rapidly but the much elongated nose or trunk remained. This is the true story of how the elephant got its trunk. The cheek teeth or molars now became greatly modified for grinding dry vegetable food. The cusps on the crown of the tooth became united into transverse ridges and increased in height, while the valleys between deepened and became filled with cement. The number of these tall plate-like ridges multiplied and reached a maximum of twenty-seven in that extinct giant among elephants known as the mammoth which was contemporary with

early man. It lived in regions where the climate was Arctic in severity. From time to time frozen carcases have been found in Siberia, which with their coating of long hair gave a very complete picture of this monster.

A Meditation

Glancing back over the last few chapters an impressive fact emerges. It is that this diversity, this multitude of mammalian types, has been produced from the same hereditary stock of bones and muscles, nerves and blood vessels by changes in the size of this, the shape of that, and the suppression of the other. For most parts of the body, in each case, the changes are relatively slight, but for a few they are so striking that we say they have been specialized, or even highly specialized, as for example the foot of the horse, the carnassial of the tiger, the grinder of the elephant. Having once become specialized there is no going back, the lost toes of the horses will never return, the teeth of the tiger and the elephant will never regain the simplicity of the teeth of the ancestral insectivore. Once specialization begins it continues until the limit has been reached. Then comes slow degeneration or rapid extinction.

37

THE ARRIVAL OF MAN

In the last few chapters we have been tracing the evolution of the vertebrates through a succession of grades from fishes, through Amphibia and Reptiles up to Mammals. At this point it will be useful to emphasize a principle which has been emerging while the process has been followed from age to age. Animals belonging to each of these grades are with us to-day. It is, however, important to realize that the animals belonging to these grades have not been at a standstill as the eras have passed by. The fishes of to-day are not identical with those that

lived in Silurian and Devonian times, before the Amphibia had begun to put in an appearance. Though fishes have remained in the fish grade for the last 250 million years they also have evolved as fishes. In such fundamental respects as breathing by means of gills, having fins and not legs, eyes but no ears or nostrils, they still reproduce the ancestral condition. But in other respects such as the presence of a gill cover, of thin overlapping scales and numerous bones, well-ossified skull and backbone, they have left the ancestral condition far behind. Similarly the frog and the lizard, while reproducing features essential to their ancestors, have specialized in many other respects and, therefore, cannot be quoted as furnishing a correct picture of the ancestral amphibian or reptile.

This same principle applies also to the phases in the evolution of man from the lowly mammals. These phases are exemplified by various animals that are alive now. The earliest phase is represented by the little tree shrews; the later, by the lemurs, the tarsiers, the monkeys, and the apes. These animals, however, are not exact replicas of man's ancestors. They are caricatures showing resemblances, fleeting but nevertheless fundamental. Bearing this in mind it is possible to redraw, in outline, pictures of the successive ancestors of man by stripping these living 'collateral ancestors' of their specialized features. Thus for example the chimpanzee has become highly specialized for living in the trees, not so much for running along the branches, as for swinging from bough to bough. To this end its arms are longer even than its legs. This gives it a more extended reach for swinging along. Its fingers also are long and flex easily into a powerful hook. For this purpose the thumb is an obstacle rather than a help and is correspondingly modified in position and size. On the other hand many features that man and the chimpanzee share point to a common ancestor that did not spend all its time in the trees, but had a bodily structure that enabled it to make the best of two worlds by running, walking, and hunting for food on the ground and retiring to the trees as a refuge and a dormitory. When, therefore, the uninitiated, after watching a chimpanzee up to its antics at the zoo, ask, 'Did man really come from apes?' the answer is 'Not

from apes as we see them in that cage, but from apes as their ancestors were 30 million years ago.'

Preliminary Outline

Keeping these principles in mind we may now try to reconstruct, in its broad outlines, the story of Nature evolving man. This is based primarily upon evidence collected from the comparative study of man and his other Primate relatives; checked and made more precise by the study of fossil remains. Unfortunately the latter are rare and scanty.

The common ancestors of all modern mammals, including the Primates, were small animals, only a few inches long, that escaped extinction in a Jurassic world dominated by reptiles because they took refuge in the trees. During late Cretaceous times many of them descended to the ground and began to occupy domains that were being vacated as the reptiles declined. A few, however, remained in the trees and became the forerunners of all the Primates. They were still diminutive creatures like the tree shrews that fed on insects, or on tender leaves and shoots. Hidden by the foliage and endowed with hands and feet that could grasp the boughs and twigs, they traversed in safety the narrow and precarious pathways of the trees and so were safe from the pursuit of primitive carnivores.

Fossil evidence for the existence of these creatures and of the later lemurs, tarsiers, and monkeys which arose from them are rare, for their bones were small and inconspicuous and are easily overlooked. Moreover the woodlands and forests where they lived were not areas where alluvium and similar deposits usually accumulated. Nevertheless trees were occasionally torn away from the banks of rivers in times of flood and were carried with their inhabitants long distances, and their remains were scattered and buried on the floor of some lake or on the neighbouring river plain. Among the many remains of mammals that have been preserved in this way, fragments of the skeletons of primates have been found. To a layman these fragments may seem meaningless, but to one who has studied the anatomy and handled the complete skeletons of living types every curve,

bump, and hollow on a bone is full of significance. Nevertheless by a brief comparison of the heads and hands of a series of primates even a layman may gain some insight into the methods of the expert.

In side view the head is seen to consist of two main parts – the face and the brain case. A line drawn from the eye to the ear roughly defines the boundary between the two. Passing

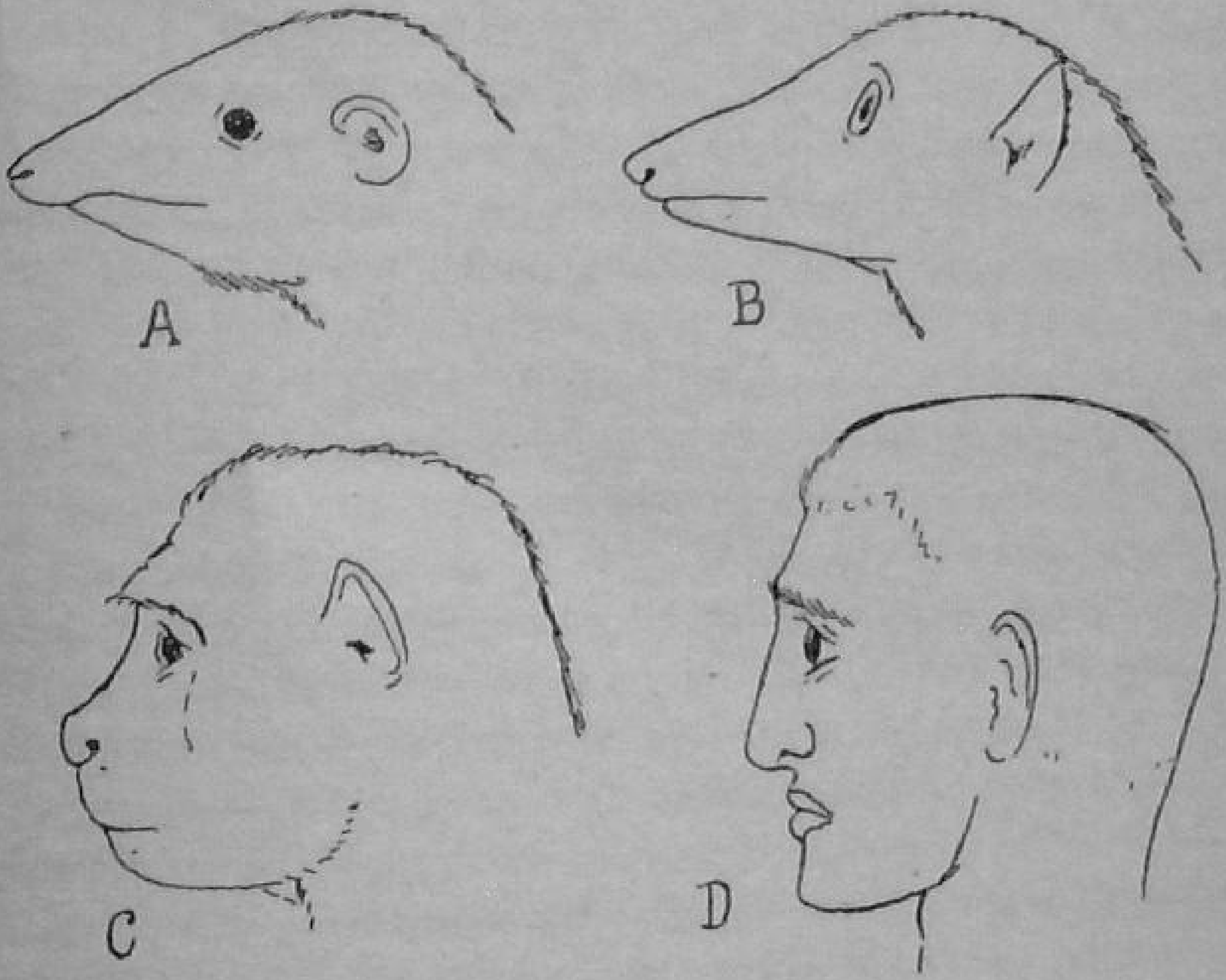

FIG. 25. TYPES OF HEAD AMONG PRIMATES

(a) Tree shrew. (b) Lemur. (c) Monkey. (d) Man

from cage to cage in a zoo or from case to case in a museum it will be seen that a series of primates exhibit progressive differences in the shape and relative proportions of these two parts. In the tree shrews, as in the majority of mammals, the face is large and snout-like and lies almost wholly in front of the brain case. It consists of a large mouth below and a capacious nose above, for mammals generally track friend and foe and search for food by the sense of smell. Going from the lemurs past tarsiers, monkeys, and apes to man it will be seen

that the snout becomes relatively smaller, for in them the sense of sight gradually replaces that of smell in all their varied activities. The nose becomes correspondingly reduced until eventually in man it is small and is of little more than aesthetic usefulness. Meanwhile the brain with its bony casing enlarges and extends forward until it overtops the face which then has an almost vertical profile. Associated with these changes the eyes, which in other mammals look sideways and act independently of one another, gradually become re-orientated into a position in which both are looking forward and, acting together, can be focused upon any object far off or near at hand. Distances and directions can thus be more accurately estimated, a fact which is of great value both on the ground and in the trees.

In early Tertiary mammals both feet and hands had five digits. In later times these often became reduced in number and specialized in various ways. In the primates, however, the primitive number was retained. While all the digits could be slightly splayed, the first digit could be spread out widely from the rest and swung round to meet the others for the purposes of grasping. Again the limbs were bound to the body only at the first joint, the shoulder and hip. This gave much greater freedom of movement than was the case in other mammals in which the upper part of the limb was bound by skin to the side of the body. Thus equipped, the primates were able to face up to and derive pleasure from the dangers of arboreal life. A false step or a slip might lead to broken limbs or even death. Under the control of the developing brain, assisted by eyes adjusted for judging distances correctly, the loose limbs could be shot out swiftly in any direction, the hand could clutch quickly and firmly at a passing bough; the terrifying fall was thus turned into an enjoyable swing, and life and fun were snatched from danger and death. In response to this agile use of the body and its organs the brain developed yet further in complexity and relative size.

Another very important feature about arboreal life is that the body as a whole must often assume an erect attitude, especially when the animal is either climbing or swinging. A

corresponding adjustment of the internal organs also took place. This important trend in the evolution of the primates was most marked in those that spent some of their time upon the ground. Here they learnt to walk and run with the body erect and were able to do so because, like the most primitive mammals, they could still plant the whole of the foot, sole, as well as toes, upon the ground. They had, therefore, a stable base upon which to stand. Their front feet, released from walking, became more perfectly developed as hands and could be used for picking up food or for holding or even throwing sticks or stones.

With this progressive attainment of an erect attitude the backbone took on the function of a pedestal upon the tip of which the head was neatly balanced. At this point, where the backbone is attached to the skull, there is a large hole, the foramen, through which the spinal cord passes on its way to merge into the brain. In other mammals the backbone is horizontal. The skull, therefore, lies in a line with this, and consequently the foramen lies at the back. Moreover, the upper margin of the occiput, or junction surface of head and neck, is marked by a prominent bony ridge by means of which the neck muscles secure a firm hold upon the head, and are, therefore, able to keep it horizontal even when the mouth is heavily laden with food. With the assumption of an erect attitude this need no longer exists and the ridge declines.

Early Primates

Keeping in mind this outline of the story of human evolution, based upon a comparative study of the living primates, we are able to appreciate some of the features of interest revealed by the scanty and fragmentary fossils that have been found and, in addition, gain an idea of the times when these changes took place.

Among the fossil mammals found in deposits laid down at the dawn of the Tertiary era were the remains of a group of small forms having affinities with the tree shrews, lemurs, and tarsiers. In them the brain had begun to evolve more rapidly

than in other mammals and the changes in the face and brain case, described above, had already set in. The fact that they had advanced so far at that early date in mammalian history shows that the evolution of the primates must have started still earlier during Cretaceous times.

The most primitive member of this group was *Plesiadapis*, a tree shrew closely related to the Mesozoic insectivores, but with a larger brain and with cheek teeth that in some respects resembled those of the lemurs. In later Eocene times true lemurs existed. Then follows a long gap in the record, during which the lemurs disappeared from the New World and migrated southwards in the Old World. Their remains were next found in the Pleistocene of Madagascar, where they are quite numerous and varied. Some of them attained almost giant proportions. By becoming further specialized for arboreal life they diverged from the main line of primate evolution and, therefore, pass out of our story.

Returning once more to the primates at their dawn, attention is attracted by *Tetonius*, a forerunner of the tarsiers. In addition to showing a still further enlargement of the brain and reduction of the face, its eyes looked fully forwards. In the skull the orbits were completely encircled and partially backed by bone. This backing became complete in higher primates, thus shielding the eyes from disturbance by the working of the jaw muscles and providing a means for a steadier control of the eye movements.

During the Eocene the tarsiers became relatively numerous in the northern continents. From that time onwards there is a gap in the record of their history during which they also declined, to such an extent that today they are represented by only one genus, *Tarsius*, living in the forests of the East Indian Archipelago.

In some of the Eocene tarsiers the teeth have features characteristic of the higher primates and thus foreshadow the coming of the monkeys. These animals, which are larger than the tarsiers, are still small enough to run about and live in comfort in the trees. Though they usually run on all fours, they sit down to eat, and consequently their hands are free to

hold their food. The earliest true monkey, *Parapithecus*, is known only by a lower jaw collected from the Oligocene of Egypt. While this retains features reminiscent of the tarsiers it shows others that are anticipatory of the apes. By continuing to lead an arboreal life they also diverged from the main line of primate progress. To-day they abound in tropical and equatorial forests. From the Oligocene of Egypt also comes the jaw of a true, but primitive, gibbon-like ape called *Propliopithecus*. This jaw was larger than that of *Parapithecus*. In its relative shortness and greater strength and in the square-crowned molars armed with four or five blunt cusps it closely approached the apes. Its appearance on the scene at that early date indicates that the apes evolved directly from the tarsiers and thus by-passed the monkeys. During the early Miocene their evolution was continued in Central Africa from whence they spread later to southern and south-east Asia.

The most frequently found fossil remains are those of *Dryopithecus*, which, though it showed features indicative of an ancestral relationship to the modern apes, was of more slender build. Even so, the primates at this stage had increased to such a size and weight that they could no longer live and sleep in safety in the trees except on the stronger branches. They accordingly spent much of their time upon the ground. There seems to be little doubt that it will be among these early apes that the ancestors of man will ultimately be found.

The fossil *Australopithecus*, from the Pleistocene of Bechuanaland, comes excitingly close to qualifying for that proud position. Unfortunately it is disqualified because it appeared upon the scene too late, for real men had then already come into existence. In proportion to the size of the animal its brain was larger than in any other ape. Its brain case, however, was distinctly more human for, in addition to being more dome-shaped than in the apes, it extended farther forwards over the face and backwards over the occiput. In the latter the foramen faced downwards and the bony ridge along its margin was rounded off. These features, together with others seen in the rest of the skeleton, particularly in the hips, show that it normally stood and walked like a man.

The First Men

In the year 1889, following closely on the heels of the Darwinian controversy, a Dutch medical man, Dubois by name, commenced excavating in fossiliferous volcanic deposits near Trinil in Java. Among the many bones he unearthed were a skull-cap and parts of the limbs of a primate which was hailed by some as 'the missing link', a phrase which crudely interpreted the name *Pithecanthropus* (ape-man) *erectus* given to it by its discoverer. In the fourth decade of the present century further remains of this 'Java Man' were found in the same deposits and added considerably to our knowledge of his peculiarities. These remains, like those of the mammals found with them, owed their burial and preservation to natural causes. Other and even more interesting finds had been brought to light in the previous decade by the work of the Canadian anatomist, Professor Black, in a cave some forty miles from Pekin. Here were found portions of the skulls of fourteen individuals and the bones of many others. After the scarce and scanty evidence for the early history of the lower primates it is refreshing to be confronted with such an abundance of material. Early man was even more wary than the lower primates and was, therefore, less liable to be caught by natural catastrophes. Fortunately, the habitations he occupied and the social customs he was developing were such that he was much more frequently buried under conditions favourable to the preservation of his remains.

'Pekin Man', for such was the popular name attached to this cave-dweller, was slightly more advanced than the Java Man. But the two resemble one another so closely that they are referred to different species of the one genus.

Pithecanthropus was 5 feet high and had a brain size midway between that of the highest apes and of modern man. Its degree of development is reflected by the shape of the brain case. His brain was larger than that of *Australopithecus*, but the configuration of the brain case and its relationships to the face and the occiput were closely similar. The mouth projected in the form of a muzzle. The lower jaw had no chin, but, apart

from the slightly enlarged canine, the crowns of the teeth were on the same level with one another as in man.

This *Pithecanthropus* type flourished during the Lower Pleistocene. It is interesting to note that then, as now, variations comparable with racial differences existed.

In 1856, three years before the publication of *The Origin of Species* the skeleton of a pre-historic man was found in a limestone cave that opened out on the side of a ravine, known as the Neanderthal, near Dusseldorf. The appearance of the skull seemed so strange that many doubted its human affinity. One famous anatomist dismissed it as a diseased individual. Professor Huxley, however, declared it to be a lowly human being,

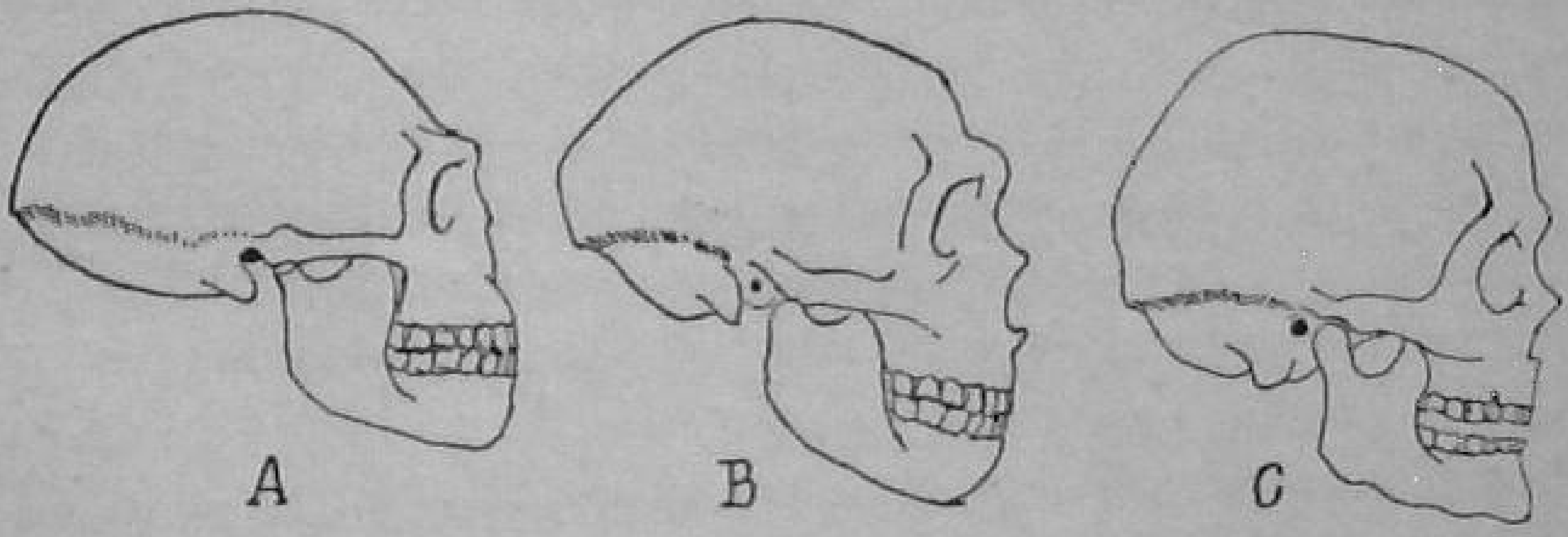

FIG. 26. SKULLS OF PREHISTORIC MEN

(a) *Pithecanthropus*. (b) Neanderthal. (c) Cro-Magnon, modern (after McGregor)

but distinctly ape-like in some respects. Since that date many examples of the same type have been found in other parts of Europe. Indeed one sample had been found at Gibraltar in 1848, but had been laid aside. Other examples have since been found also in Siberia, North Africa, and Palestine. All conform to the same human type, known as Neanderthal Man, and were referred to the one genus *Homo*. Some are distinctly more primitive and show closer affinity with the ancestors of modern man. Others have specialized in directions leading away from the main network of descent.

Remarkably complete skeletons have been found so that the appearance of Neanderthal Man is well known. He was 5 feet 4 inches tall and walked with a slight stoop and bent knees. He was powerfully built and had large hands and feet. His brain

was the same size as in modern man, but was less fully developed in front and above. These differences are reflected in the shape of the brain case. In this the forehead was low and receding. The crown was also low and sloped back to its junction with the occiput which had lost its ridge-like character and, though rounded, was still slightly angular. The occiput, with the foramen, faced downwards and slightly backwards. In cross-section the cranium was bun-shaped with bulging sides. The mouth projected a little distance in front of the vertical plane of the face. The lower jaw was powerful, but was still without a chin.

The earliest trace of the existence of this type of man is a jawbone found in gravels which dated from the Lower Pleistocene, but the majority of finds belong to the early part of the Upper Pleistocene; that is to say to the last interglacial, and the first phase of the last glaciation when the climate in Western Europe was cold and even severe. It is not surprising, therefore, that this type of man, *Homo neandertalensis*, was predominantly a dweller in caves.

The third and last type that now comes up for consideration is Modern Man, *Homo sapiens*. Many fragmentary and even complete skeletons are now known from various places in Western Europe. Swanscombe Man, the earliest of these, was found in gravels of the 100-foot terrace in the Thames Valley. They were laid down during the long interglacial and thus date back to the early half of the Middle Pleistocene. The remains consist of two large fragments of the cranium which were sufficiently complete to show that the brain case had the high dome and flattened vertical sides which characterize Modern Man.

The majority of the remains date from the latter half of the Upper Pleistocene when, in North-western Europe, the climate was often intensely cold, and man sought shelter in caves. Among his remains a wide variety of racial types has been recognized. One of these was very tall with an average height of 6 feet 4 inches. Features in the leg bones show that he was a swift runner which, since he had not yet caught and tamed the horse, was a great advantage as he had to do all his hunting on foot.

The front and upper parts of his brain were more fully developed than in Neanderthal Man. This is proved by the shape of the brain case which had a high domed roof, flat vertical sides, and a well-marked forehead. The mouth no longer projected like a muzzle, and the lower jaw had developed a chin.

Considering that it is no more than a century since interest was aroused by the finding of the first skeleton of prehistoric man in the caves of Gibraltar and Neanderthal, it is not surprising that great gaps still exist in our knowledge of the early history of *Homo sapiens*. For reasons explained earlier, excavations have been confined mainly to Western Europe. This work is now being extended to other parts of the world, especially Africa, and will surely lead to many new and illuminating discoveries.

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THE GOSSAMER NETWORK

BEFORE passing on to glance at man's intellectual progress as reflected in his handiwork we may pause for a while to meditate on one underlying and very significant feature of this long, long story that started with a nebula, and culminates in man. In common with the other animals and plants, man commences his separate and individual life as a single cell. Supplied with sustenance and energy from the inexhaustible bank of its environment, it grows. As it develops it passes through stages in each of which may be detected features reminiscent of the successive grades of animal life from the lowest to the highest. The fossil remains found in the rocks, though fragmentary and rare, furnish sufficient glimpses of the animal life of past ages to show that these grades mark out the pathways along which living things have been evolved. From all this it is evident that by means of some mysterious agency or process known as heredity, man, along with the ape and tree shrew, the crab, the octopus, and the butterfly, is an heir of all the ages.

This twentieth century has witnessed an amazing amount of progress in the investigation of the hereditary process and its mechanism. With characteristic ingenuity and praiseworthy anxiety for the welfare of his fellows the scientist has applied this new knowledge to the improvement of man's crops and stocks, not forgetting the beautification of his gardens. Many more chapters could be written about his achievements in these directions, but that would take us far outside the scope of this book. It is, however, right and proper that at least this very brief reference should be made to the contribution the workers in this field have made to the general story of the earth and its inhabitants. Not less important, however, is the contribution they have also made to human thought.

It has already been seen that single-celled animals multiply by fission. That is to say, each individual grows to a certain size and then, instead of dying, divides into two parts each of which grows and in turn divides. Gradually the vigour of the stock diminishes and the rate of fission declines. At such times two individuals may come together, almost fuse with one another, and exchange portions of their nuclear substance. After that they separate once more, grow, multiply, and live with increased vigour.

A great step forwards in organization was taken when, instead of the individuals formed by fission separating, they remained united and became parts of one larger body, the soma. Within the soma the great majority of cells were in due time specialized and grouped into tissues and organs for greater efficiency in the performance of different functions. A few cells, however, were not thus specialized, but retained the primitive plastic condition of the parent cell. They grew, multiplied, and separated from one another within a deeply seated part of the body known as the gonad, or reproductive organ. These cells, when mature, are called gametes and are of two kinds usually produced in different individuals, male and female respectively. The female gamete is called the egg cell; the male gamete, the sperm cell.

Before an egg cell can develop and grow into a new plant or animal a sperm cell must enter into it and fertilize it. The

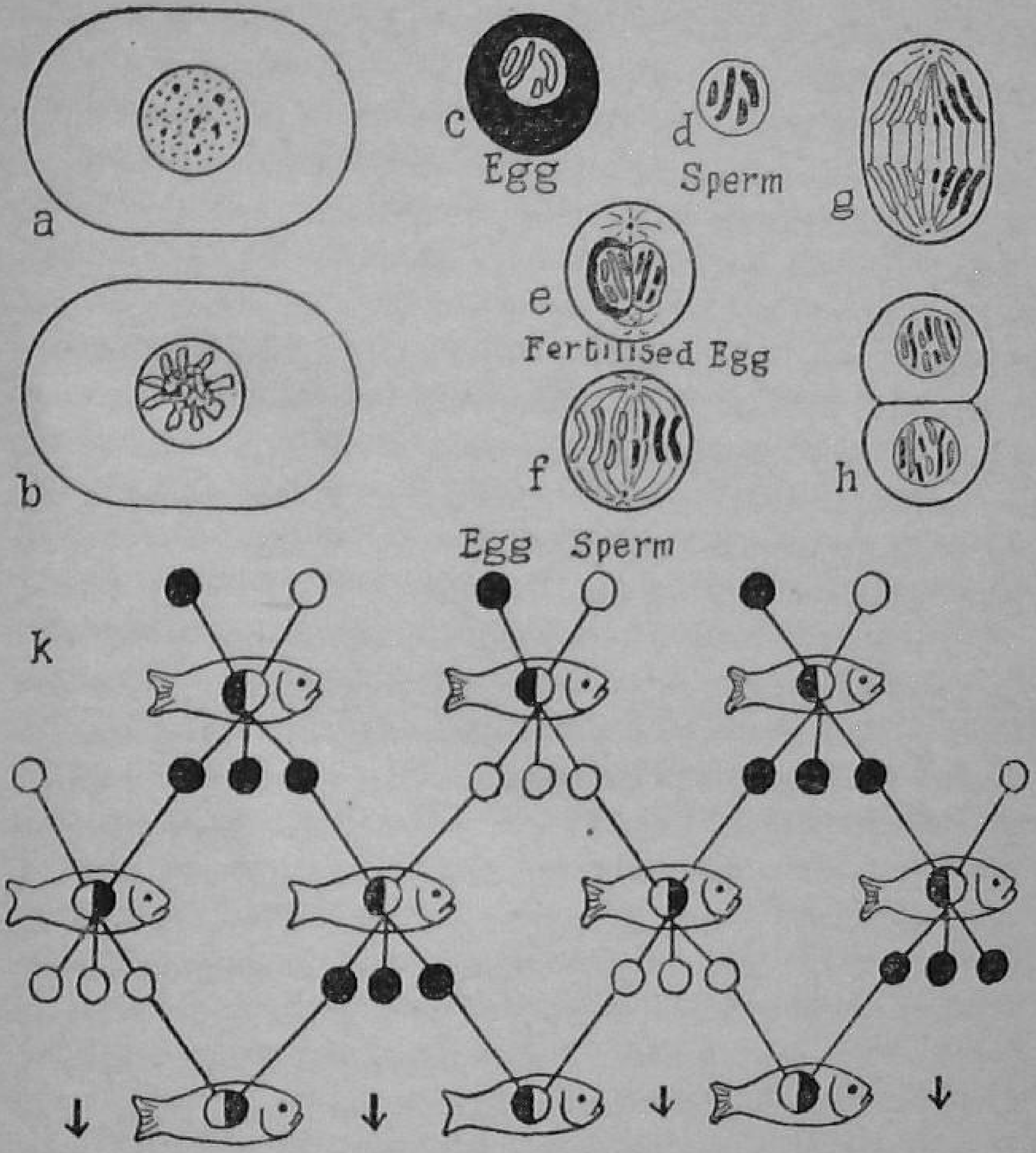

FIG. 27. THE MECHANISM OF HEREDITY IN EVOLUTION

(a) Cell with nucleus in a normal state. (b) Cell with hereditary material gathered together into a thread in the nucleus (×800). (c, d) The thread broken into segments or chromosomes, each of which contains many genes. (e) Fertilized egg produced by the fusion of egg and sperm. (f, g) Cell being prepared for division by the halving of each chromosome. (h) Cell dividing. This process (*a–g*) is repeated until the soma or body of a fully grown animal (e.g. fish) has been formed. (k) Such changes have been repeated in every generation down through the ages. In each generation the body dies but part of the germ-plasm or hereditary material is passed on by means of the sex cells (egg and sperm)

nuclear substances of the two cells are then most carefully sorted out, and intimately intermingled, in a series of very wonderfully devised movements of some of the minutest

particles that the microscope has ever revealed. When the intermingling is complete, the egg cell develops into a new plant or new animal leading a wholly separate existence from either of the two parents. The parents die, their bodies perish, but some of their germ substance, or germ-plasm, has not died. It lives on in the gametes of their offspring. This germ-plasm is, therefore, like a slender gossamer thread linking parent to child. Two threads, one from each parent, are, as it were, knotted together in the fertilized egg cell.

The child grows to maturity and ultimately another child is born, produced in like manner by the union or knotting of two more threads of germ-plasm from different parents. Thus another mesh has been knitted in the gossamer network of germ substance that links every member in the living garment of the present with the individuals of all the generations of the past, back to the single-celled ancestors that lived some 1500 millions of years ago, and through them with the atoms and other physical entities which made up the liquid world and the gaseous nebula.

The great stability of this germ-plasm is reflected in two sets of facts. On the one hand is the re-enacting, during the development of each individual, of the main phases in the progressive evolution of animals from the single-celled condition through the various grades of structure up to the highest. On the other hand is the very close similarity of the offspring to the parents and to the parental stock.

This similarity, though close, is not identical. The intermingling of the germ substances from two parents provides an opportunity for shuffling the characteristics of the two parents and for dealing out different 'hands' to the children, with the result that no two of these are exactly alike, nor does any one of them exactly resemble either of the parents.

From time to time new features appear in the offspring which have not occurred in the race before. This fact implies the introduction of a change into the make-up of the germ-plasm. It was pointed out earlier that every new arrangement of electrons, atoms, and molecules is a new step in the process of evolution; a step which conveys to our senses and experience

some new impression or message. A similar procedure has been pursued through all the generations of living things. Step by step there has gone on a progressive building up of the germ-plasm, some new arrangement within its structures, some new entity, called a 'gene', has been introduced that leads to the development of a new feature in the fully grown animal or plant.

Packed away in each gamete are numerous genes which, in ways not yet understood, are the means used for guiding the growth of the several parts of the body to their full development. In other words germ-plasm is the physical basis of heredity, and heredity is true to form because germ-plasm is so stable. It is so stable because it has been built up by a long succession of carefully conceived steps, each involving the delicate and complicated operation of inserting a new gene into an already very complex structure in such a way that the new feature grows and fits in harmoniously with the other parts of a very intricate organism that is not merely ready to grow, but is actually growing. Thus there has been produced among living things in this world an ever changing unity, that is in harmony with that of the universe as a whole. This unity is too often lost sight of in the midst of our various specialized studies. We have dissected and disarticulated this unity and have labelled the study of its dismembered parts with such names as Physics, Chemistry, Zoology, Geology, and the like. It is, therefore, a good thing, now and then, to put away our test tubes and thermometers; to pack up our scissors and scalpels; go forth from the laboratory, and give time to the contemplation of Nature, this mighty whole that is throbbing with energy and life, with thought and feeling, with gaiety and love.

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A CREATIVE CRAFTSMAN

THE most familiar and most generally useful tool that man possesses is a pocket-knife. It is always ready to be used for

any one of a multitude of purposes from the sharpening of a pencil to the peeling of an apple. Even before the days of pockets men had knives. Indeed the earliest tool man made was essentially a knife with which he could sharpen the end of a stick to be used as a spear or javelin for disabling an animal he could not quite catch. Having caught his victim he skinned it. Being unlike a dog he had no piercing canines, no slicing carnassial teeth, but his knife served the same purposes and enabled him to cut or chop the flesh into pieces ready for eating. With it he could also grub in the ground for edible roots.

At first, no doubt, he made use of sharp-edged stones broken by natural accidents. To-day many such stones may be picked up, but it is practically impossible to say with certainty of any one of them, 'This was used by early man'.

It was a great step forward when man discovered that he could make sharp-edged stones easily and in abundance for himself. Some of the oldest known tools made by man have been found in the pre-glacial gravels of central Africa. Evidence based on these shows that he made use of medium-sized pebbles to which he gave sharp edges or pointed ends by knocking off flakes. Such tools, crude as they were, could be used for piercing, cutting, and chopping.

From deposits yielding the remains of *Pithecanthropus*, in caves near Pekin, evidence has been obtained which shows that man also used boulders. By smashing these one against another he produced smaller pieces which he could shape by further flaking.

In later times boulders were dealt with more skilfully. This was demonstrated by the work of Mr F. Spurrell in 1879 at Crayford in Kent. Here the 'floor' of a prehistoric tool factory was discovered littered with innumerable flakes often piled up in little heaps. He conceived the idea of collecting all the flakes from one heap. By piecing these together, in jigsaw-puzzle fashion, he reconstructed the boulder as it existed originally. In this way he found that it was irregular in shape, 10 inches long by 6 inches deep. From it at least sixty flakes had been removed until only a small core remained which, however, broke and could not be used for conversion into a tool. This method of

producing raw material for making tools prevailed throughout the Stone Age.

A cursory inspection of the tools of different periods shows that man's technical skill gradually improved and, from a closer examination, some idea of his methods may be inferred. Fortunately other sources of information exist. Thus, for instance, some of the aborigines of Australia and elsewhere still live under Stone Age conditions and much has been learned in recent years by watching them at work making and using their tools. One of the many interesting facts that have emerged is that with a sharp-edged stone a small tree can be cut down. In addition some archaeologists have themselves become proficient in such stone-craft and can, therefore, speak with an authority based on personal experience.

From the vantage point of present-day knowledge of rocks we now see that stones differ greatly in amenability to treatment. Many have a marked structure of their own. Like a lump of coal, they cannot be trimmed to any useful shape because they split so easily in wrong directions and regardless of the worker's intentions. Other stones are more like lumps of glass. They have no planes of easy splitting, but are almost uniform in texture. The direction which a split takes, therefore, depends upon the way in which a blow is delivered and is consequently under the control of the tool maker.

Nothing of all this was known to our forebears who lived nearly a thousand centuries ago. Endowed physically with fingers and thumbs and mentally with an insatiable curiosity and a retentive memory, they handled and played with anything loose that was lying about. Scores of them were up to the same game watching and imitating one another. Thus their observations and experimental results were pooled. Experiments were repeated endlessly. Unsuitable stones were rejected, suitable ones subjected to further attention, and the ability to recognize particular stones again was acquired. In some such way as this man discovered that flint was almost ideal for the purposes he was gradually developing. In areas where flint does not occur he found a second best in other stones, in quartz, quartzite, or in fine-grained igneous rocks.

As man's powers of communication and speech developed, the various results arrived at in these incipient schools of research were passed on from community to community, from generation to generation. Men came, men went but the genes of new discovery were transmitted, and the gossamer network of knowledge evolved to its present complexity and wonder. We are where we are, not because we are better equipped mentally than they were, but because they laboured and we have entered into their labours. It must be with such thoughts as these that we set out to make a rapid and very brief survey of the material relics of the early stages in the evolution of human craftsmanship.

Of all the materials handled by man stone was the least perishable, and consequently the relics of his handiwork in stone predominate. The first of these to be recognized as such were found near Gray's Inn Road, London, in 1690 and at Hoxne, Suffolk, in 1797. By the end of the nineteenth century many similar tools had been found and considerable progress had been made in reconstructing the prehistory of Western Europe. To-day that story is more fully known for that region than for any other part of the world, and consequently it provides the substance of this very brief account. Nevertheless, many gaps still remain which can be filled ultimately only as the exploration of other regions extends. Progress in this work has already started and is rapidly gaining momentum.

In making core tools the chips were knocked off by hitting the pebble or boulder with or against another stone. At first the flakes were relatively short and thick and consequently the two surfaces of the implement were marked by deep hollows separated by prominent ridges. The cutting edge, formed by the intersection of the surfaces, was not straight but zigzag. Such was the general standard of workmanship attained during the Lower Pleistocene. The first implements of this type to be recognized and fully described came from the terraced gravels of the River Somme at Abbeville. The stage of culture they represent is known as the Abbevillian.

During the Middle Pleistocene man's technical skill improved as the outcome of continual practice and the discovery of new

methods of working. Probably the latter involved the introduction of cylindrical pieces of soft stone or wood or bone, which were used like a punch by holding one end against the flint and hitting the other with a hammer stone. In this way thin elongated flakes were skimmed off and a smooth surface was given to the tool, marked only by faint hollows and feeble

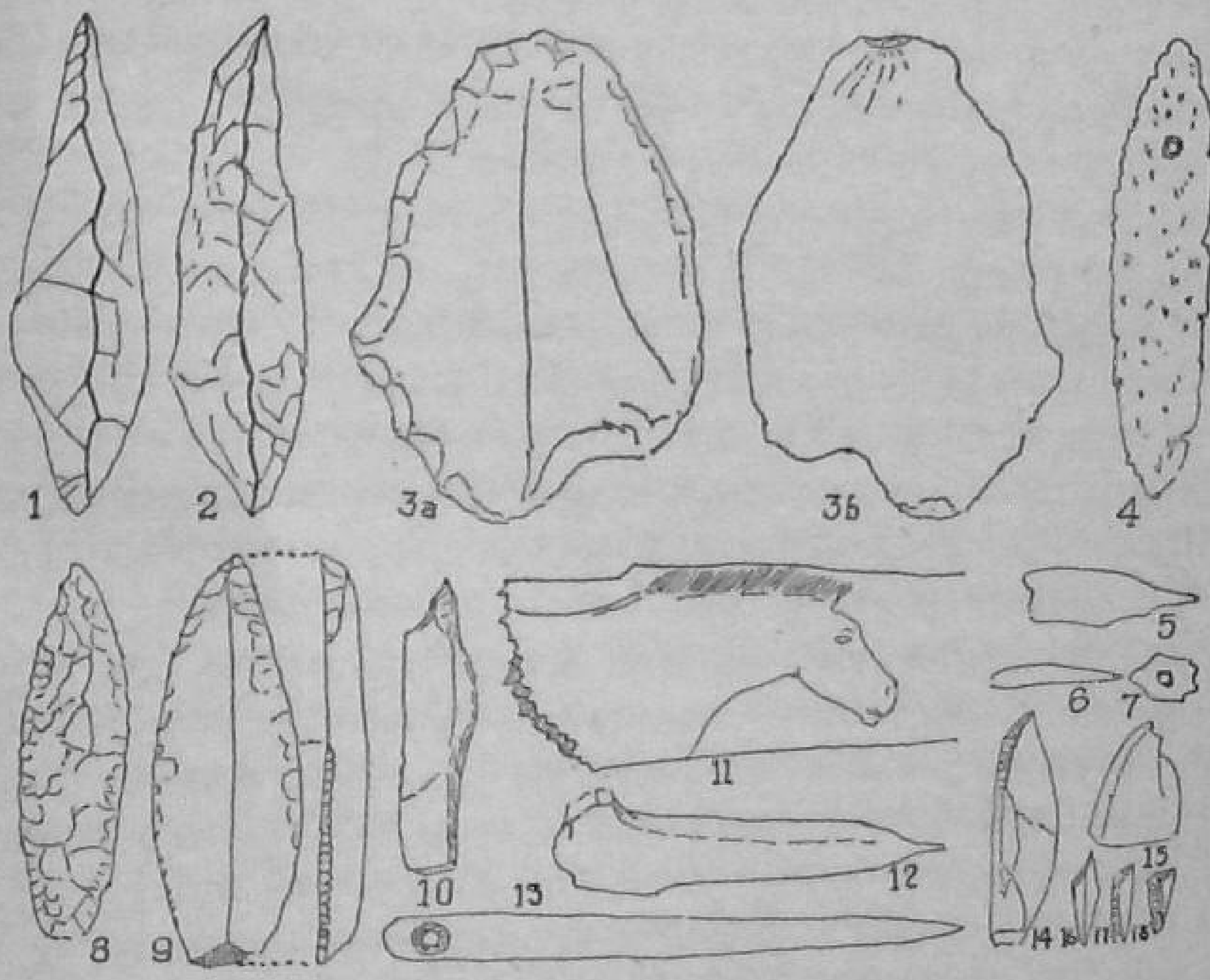

FIG. 28. EARLY AND MIDDLE STONE AGE RELICS

(1) *Abbevillian.* (2) *Acheulian.* (3) *Clactonian.* (4–7) *Mousterian* – bull-roarer; bone awl, needle, and bead. (8–13) *Aurignacian:* (8) Flint point with solutrean trimming. (9) Flint blade trimmed only on the edge. (10) Flint awl. (11) Drawing on bone. (12) Bone awl. (13) Bone needle. (14–18) *Mesolithic:* Tardenoisian [*after Chouquet*] (1); *Lacaille* (2); *Baker* (3); *Armstrong* (4–10), (14–18); *Boyd Dawkins* (11–13)

ridges. The intersection of these smoother surfaces produced a straighter cutting edge.

Such implements were found quite recently in the terraced gravels of the Somme at St Acheul near Amiens, and the culture they represent is the Acheulian. Implements exhibiting various stages in the development of this culture are known as

early, middle, and late Acheulian. The fact that these occur at successive levels in the gravels proves that they do really represent a sequence of improvement with the passage of time. Two shapes – ovate and pointed – are commonly present. The Acheulian culture developed in Africa from whence it was brought into Europe.

Because of their size and obviously human workmanship these core tools were the first to attract the attention of archaeologists. More recently the existence of another type of industry, characterized by the much fuller use of flakes, was discovered in gravel deposits near Clacton, Essex, and is now distinguished as Clactonian. In this a flint was used that had a flat surface which had been produced naturally or artificially by splitting a boulder. The workman, holding the flint with its flat surface downwards hit it near its margin against another stone, used as an anvil. In this way large flakes were knocked off rapidly. Many of them were used as scrapers for removing fat and bits of flesh from the inner surfaces of skins, or for softening skins that had been dried stiff. Some of the flakes have concave notches chipped out of one edge. These were probably used for smoothing and sharpening sticks to serve as spears. The pointed end of a wooden spear was actually found in a peaty interglacial deposit at Clacton.

Among the earliest flake tool makers may be counted the cave-dwellers near Pekin in Lower Pleistocene times. It is believed that the flake tool culture developed first in the Far East and was introduced from thence into Europe.

These two main types of tool culture, which characterized the early Old Stone Age or Lower Palaeolithic, evidently evolved contemporaneously in different parts of the Old World but flowed towards Western Europe in two streams which met there and to some extent mingled with one another.

In the early days of prehistoric studies a distinction was drawn between River Drift Man and Cave Man. This corresponds roughly with the makers of core tools and flake tools respectively and reflects also the differences in places of origin which have become realized more recently. The African section, in the course of its wanderings, naturally extended farthest

north during the long warm interglacial period, when conditions were most favourable to the continuation of their traditional mode of life out in the open. With the approach of the next glacial spell they retired, but the cave-dwellers, who also had appeared upon the scene, coming as they did from temperate latitudes remained until climatic conditions had become much more severe. They then departed and left the ice-fields and glaciers in sole possession, for the next 20,000 years or so, until the onset of the next more genial or interglacial episode.

These attractive distinctions, though useful, must not be pressed too closely, for at times there must have been contact between and even mingling of the two peoples which resulted in some degree of mutual modification of techniques. Core users, for instance, began to give more attention to the use of flakes, but developed their own way of producing them. This consisted in carefully trimming one part of the surface of a core, then knocking a large flake from it. This produced what has come to be known as a Levalloisian flake which has one surface quite smooth, the other already neatly trimmed, and a cutting edge which is very sharp. On the other hand, flake workers sometimes chipped both sides of a large flake thus producing a thin Acheulian type of tool. This mingling process seems to have reached its final expression during the last interglacial and the early part of the last glaciation in a culture known as the Mousterian. This was essentially a development of the Clactonian flake industry modified by Acheulian and Levalloisian influences. It was found at Le Moustier and in other caves on the Continent associated with the remains of Neanderthal Man. The period during which it lasted is known as the Middle Palaeolithic.

Deposits formed in caves have yielded abundant evidences bearing upon the habits and handicrafts of their middle and late palaeolithic tenants. Many generations of men, women, and children went in and out of these caves and squatted in the warm sunshine outside the entrance or inside around a genial bonfire. Here they roasted their joints of meat, ate their meals, and shaped their tools. Fortunately for us they were untidy

folk and scattered their litter all round. Dust carried by the wind and dirt carried on their feet accumulated on the floor and buried their litter. Thus it was preserved for our inspection and instruction. Sometimes the cave was used as a tomb, and an important person, or a favourite child, was buried in the floor. With them they also buried joints of meat and choice implements for the use of the departed in the realm to which they had gone. The caves shielded these graves from the depredations of percolating rain, thus preserving the bones and relics symbolic of some of the thoughts and feelings of Old Stone Age Man.

In the latter part of the nineteenth century a great enthusiasm for exploring caves arose and many secrets hidden in these prehistoric muniment chambers were revealed for the first time. One of the most complete sets of records has been unearthed in a group of caves in the sides of a gorge near to Cresswell in Derbyshire. The little River Poulter, running along the middle, marks the boundary between that county and Nottinghamshire. Crags of magnesian limestone wall it in on either side. These caves were first explored about the year 1875. After the lapse of half a century the work of excavation was resumed by Mr Leslie Armstrong and carried out more completely and meticulously with the aid of the most up-to-date methods.

The cave deposits varied in depth up to as much as 20 feet and consisted mainly of sand and cave earth. They were, however, divided into three parts by the presence of two layers of breccia, consisting of angular blocks of limestone which had fallen from the roof and sides of the caves, and had since become cemented by the deposition of lime from dripping water. The presence of these stones can only be ascribed to the action of intense frost upon the limestone closing the cave. The conclusion that these breccias represent the first and second phases of the last glaciation is confirmed by the presence of the bones of Arctic animals such as the mammoth and the reindeer.

The deposits of sand and soil were thus divided into bottom, middle, and top layers and were sealed in, near the surface, by a thin sheet of stalagmitic lime. Up to the base of the top layer

Mousterian implements were found. In the lowermost portions these were associated with bones of the horse, bison, lion, hyaena, and other animals, indicative of a genial climate. Higher up, however, these became scarce and those of the reindeer common, a sure sign of the approach of an Arctic climate. When eventually glacial conditions set in, man left the district and remained away as long as they lasted.

During his tenancy of these caves Mousterian Man discovered and developed the use of bone. Among the crude tools that he made from this material were some that had been 'shaped by grinding, then polished and rubbed to a fine needle point'. These were no doubt used for piercing holes in skins through which sinews could be threaded for fastening them together and making them into clothing. Small bones from the toes of various animals were found which had holes bored through them so that they could be worn as beads or as amulets. One object of peculiar interest was a flat piece of bone with a hole at one end. This was a 'bull-roarer' such as that used by witch doctors. Children sometimes make toys of a similar shape and by whizzing them round their heads rapidly at the end of a string make a strange weird noise, especially if the edges are notched.

Though no actual remains of man himself have been found in these caves, relics of the same type of culture have been discovered on the Continent associated with Neanderthal burials. Notwithstanding his brutish aspect this human type played a valuable part in the early progress of mankind.

Above the bottom six inches in the topmost layer of the Cresswell caves no further signs of Mousterian Man were forthcoming. It was during this second genial interlude in the last glaciation that Neanderthal Man became extinct, at least in Western Europe, and was superseded by *Homo sapiens*, who brought with him a new culture characterized by implements made from long blades of flint. The ample records preserved in the continental caves show three marked modifications of this culture. The earliest, known as the Aurignacian, is well represented in the Cresswell caves. The other two are practically absent. In the second, the Solutrean, the trimming of these long

flakes was carried to a degree of perfection hardly ever exceeded in later times. In the third, or Magdalenian, man developed a remarkable degree of skill as an artist. His drawings, paintings of animals and hunting scenes, made on the walls of his caves, and his carvings on bone have filled all those who have seen them with wonder.

In England Aurignacian Man remained in occupation of the Cresswell gorge until the passing away of the Ice Age. The flint implements he used included sharp-edged knives, arrow heads, javelin points, scrapers, for cleaning skins, awls, for boring holes in bone, and burins – curious little tools with tiny chisel-like tips with which he could scoop out deep grooves in long bones so that they could be more easily split into long splints. From the latter he made long points for arming javelins, and delicate needles with minute eyes that could be used for sewing skins together into warm garments. His flint blades were normally untrimmed, but a few show trimming which reflects a Solutrean influence. Several pieces of bone were found having drawings scratched upon them. One showed a horse's head, another a crude presentation of the human figure. These, however, are but feeble reflections of Magdalenian artistry.

Some descendants of Aurignacian Man continued to live in the vicinity of the gorge during the passage from glacial to more genial climatic conditions. That part of their story, however, will be outlined in the next chapter.

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THE DAWN OF A NEW ERA

At the time of the passing away of the Ice Age the narrow seas which now separate the British Isles from one another and from the Continent did not exist. Their place was occupied by low-lying plains. The Trent, and possibly the Thames, were tributaries of the Rhine which then traversed the North Sea plain on its way to the coast, which stretched across from Scotland to Denmark. The British area was then a broad blunt

peninsula projecting westwards from Europe out beyond the present coastline of Ireland.

As the continental ice-sheet shrunk and its margins receded the other climatic belts swung slowly back to their present positions. The tundra passed away, and with it went the open grassland, the mammoth, the reindeer, and other animals which Palaeolithic man had hunted for fun, food, and clothing. The story of the climatic changes which now took place over the peninsula has been reconstructed largely as the outcome of a careful study of the layers which make up the peat deposits of highlands and fens. The wood, twigs, leaves, nuts, seeds, and, above all, the pollen grains they contain, have been examined, identified, counted, and made to contribute their quota to the story of the reclothing of the landscape which had been devastated by glaciers and blasted by icy winds. Willow, poplar, birch, harbingers of the return of warm but still dry conditions, came stealing across the countryside dotting it with copses here and there. Then came the tall pines in closer but still relatively open formation, with undergrowth of hazel bushes. About 7000 B.C. the warm dry Boreal period, as it is called, became established. The coniferous forests gave way before an irresistible invasion of oak, elm, lime with more hazel. With this temperate woodland came also multitudes of insects and birds, furred animals small and large – mice, hares, boars, and deer.

All these changes involved a progressive limitation of man's living spaces. In the tundra he could hunt and move about in all directions. In the coniferous forests his movements were not quite so free. In the mixed woodland conditions were more varied. On the moist soils of low-lying clay lands the vegetation was lush and patches of almost impenetrable forest developed. Open woodland, however, remained in situations less favourable to luxuriant growth, such as the thin soils of the Palaeozoic highlands of Wales, Scotland, and the north of England, the windy crests of the chalk and limestone scarplands, and the dry sterile grounds of the Triassic sandstones. Towards the end of the sixth millennium B.C. the dry Boreal conditions ended and the warm moist, eventually wet, Atlantic period set in. The dense forests extended and encroached on but did not eliminate

the open woodlands. It was in the latter that the scanty human population still found corridors along which to travel and broader spaces in which to eke out a living by readjusting its habits to conditions which were becoming increasingly unfavourable to their traditional mode of life. This readjustment is reflected in the relics of man's craftsmanship. The type of culture that developed and prevailed during the dry Boreal period and the onset of the moist Atlantic period is referred to as the Middle Stone Age or Mesolithic.

The Cresswell gorge was well placed for late Old Stone Age man to win some sort of a livelihood. With its crags and caves it ran athwart the minor scarpland of the magnesian limestone. Though, beyond its western end, dense woodland ultimately developed, on the east it opened into an extensive area of sandstone country upon which the open woodland grew and persisted far into historic times, when it became the stage for the exploits of Robin Hood and his merry men and, for centuries, was kept sacred as a royal hunting ground.

Here Aurignacian Man continued to live and succeeded in adapting himself to the changing conditions, usually camping out in the open, but during inclement spells of weather retiring to the caves for warmth and shelter. He now hunted red deer, boars, and oxen instead of reindeer, and snared or shot birds and small mammals. For some unknown reason he reduced the size of his flint implements until they were so small that they are now frequently referred to as 'pigmy flints', though he himself was far from being a pigmy. The majority were slender triangular blades devoid of trimming except for the blunting of one edge by very delicate chipping. Probably they were mounted in wood and used as points for arrows, darts, and javelins. Many such smaller flakes were shaped like equiangular triangles and other geometrical figures and may have been used as teeth for arming wooden harpoons.

Elsewhere, throughout the woodlands of Europe, man also lived a more restricted life than formerly, and was adapting his ways and works in a similar fashion. This widespread type of culture, known as Tardenoisian, was introduced into Britain from the south, and may have had some influence upon the

Cresswellian industry. These Tardenoisian folk seem to have been familiar with the dog and may have made use of it for finding animals hidden from view in the undergrowth.

Two other important related cultures have been recognized. One of these, the Azilian, developed in coastal areas where the normal sources of food were augmented by fishing and collecting shell-fish. The canoes from which they did the former were of use to them in their migrations northwards along the western seaboard. Azilian camping grounds have been found situated on the 25-foot terrace along the Scottish coast in the neighbourhood of Oban.

The most successful variant of the Mesolithic culture was the Maglemosian which arose and developed between the Seine and the Baltic. One element contributory to its success was the discovery of the way to make a flint axe with a straight edge which could be used for felling trees and for shaping and hollowing the trunks into canoes. The Maglemosian people haunted the margins of lakes and rivers, and areas which were occupied by marshes and fens swarming with fish and wild-fowl. They spread westwards into Britain, a movement that was favoured by the gradual submergence of the North Sea plain which was now taking place. An almost necessary preliminary to the final inundation of each section of these low-lying lands was a deterioration in the efficiency of the natural drainage which was accompanied by the development of peaty marshes and fens. In such new surroundings they felt quite at home. Here they caught fish with spears that were armed with two bone prongs, each of which was pointed sharply and had its inner edge neatly notched like a harpoon. A fish caught between the prongs could be easily pulled out of the water. One of these was found in a piece of 'moorlog' or peat that was dredged up by a modern fisherman from the floor of the North Sea not far from the Dogger Bank. In recent years one of their occupation sites was discovered beneath the alluvium of East Yorkshire, and as the result of careful excavation, conducted by Professor J. G. D. Clark, much new light was thrown upon the life of the Maglemosian people.

Notwithstanding all the courageous efforts made by the

Mesolithic folk to cope with changing conditions in their environment they laboured under one grave disadvantage: they were still in bondage to the traditional and precarious habit of merely collecting their food from the landscape. Unfortunately for them the coming of the Atlantic type of climate intensified their difficulties. Moreover, in addition to curtailing their hunting grounds, the new conditions failed to provide them with opportunities and incentives for breaking loose from the grip of tradition. The reverse was the case for the peoples that lived farther south, in the rear of the migrating woodlands.

In the Near East and around the Mediterranean the summers had become drier and the winters warmer. The woodlands consequently opened out and wide spaces came into being that were carpeted with grasses and herbs, thus providing grazing grounds for gregarious flocks of wild sheep and cattle. The hunter's work was thus made much easier and his spoils more abundant. Meanwhile his women-folk and children, in the course of their daily and tedious search for food, discovered some grasses scattered about the pastures that produced seed grains large enough to be collected and used for food. Some of these were accidentally dropped in the vicinity of the camping grounds where, under the moist conditions of winter, they quickly germinated and grew, and in early summer ripened in patches practically free from weeds. Finding these less tedious to harvest than to collect at random the quick-witted women were inspired to spinkle seeds about deliberately. The pointed sticks which hitherto had been used for digging up roots and grubs now underwent a change of function and were used for breaking up the soil in preparation for receiving the seeds. After a time stone axes hafted on to handles were found to be more effective for this purpose and 'hoe culture' began. This epoch-making change over from food collecting to food production took place during the sixth millennium B.C. In a comparatively short space of time these elementary beginnings of the great and all-important industry of agriculture spread rapidly and became widely distributed.

At about the same time the hunters became shepherds and herdsmen. Here again the steps by which this change was

accomplished can only be imagined, for direct evidence is not forthcoming. No doubt man's basic love for animals, tenderness for the weak, and helpless young, and pity for creatures distressed by thirst in times of drought, played an important part in establishing friendly relations with the beasts of the field.

The whole time and energies of men and women were no longer consumed in making shifts for a living. Henceforth the efforts of only a portion of the population sufficed both to supply immediate needs and to build up stores for use at all seasons and in those lean years of drought which were the preliminary signs that, over the more southerly regions of that part of the world, a desert type of climate was slowly spreading.

Now, at last, men and women had leisure, and the new age of mental, social, and spiritual evolution was speeded on its way. The old flint-implement crafts had still to be carried on by the rank and file, for the weapons of the chase were still required for repelling the wild beasts that attacked their flocks and destroyed their crops. But new industries demanded new and better tools among which the axe was the chief. It was now possible for skilled craftsmen to specialize in making them. These specialists also went prospecting for flint and for tough stone that could serve the same purpose. Having discovered where these were to be found they learned how to open out quarries and to sink mines. They also developed the arts of sharpening the edges of their axes, and of smoothing and polishing the surfaces by grinding them with sand or on sandstone. This opening phase of the New Era is known as the Neolithic, or New Stone Age.

The grinding and polishing of stone implements was only one of the new skills that were acquired. Fresh developments gave rise to fresh needs, the pressure of which fell mainly on the women. It was they who devised and developed the art of weaving tough grasses, and possibly also the flexible withes of the willow into baskets for carrying grain, as well as the art of making leather bags for carrying water. They even lined baskets with clay for the latter purpose. Occasionally one of these was accidentally burned. The clay lining, however, was baked hard and its outside surface retained the imprints of the basket-work.

This gave them their first lesson in the art of making pottery. Though largely imaginative this story is not wholly without foundation for the earliest pots were shaped like bags and their surfaces were decorated with an imitation of basket-work. This new craft produced imperishable pot fragments that took their place alongside stone and other enduring types of implements as records of human activity of mind and body. The story told by pottery becomes more detailed and complete with every fresh excavation and would demand a whole book for the telling.

Along the fertile river plains of Mesopotamia and Egypt the soil was renewed continually by deposits from flood waters, and consequently it never became exhausted by over-cultivation. Elsewhere the case was very different. A Neolithic community having exhausted the soil in one place moved on to another, but these riverside communities were able to remain settled. The ample water supplies, combined with almost perennial sunshine, made it possible to sow seed, grow crops, and harvest them several times a year. With such abundant resources of food, the population grew, villages, then towns, and at last great cities germinated, grew, and ripened, as for example the city of Jericho which, as recent excavations under the direction of Miss Kathleen Kenyon have shown, was already a walled city during the sixth millennium B.C. Industry, trade, commerce, government, and knowledge advanced, and the mighty civilizations of Egypt and Babylonia became established. For a while they flourished, but in course of time they declined and perished.

The main stream of human progress, the farming population, flowed on. This formed the slowly changing radicle stock which gave origin, at intervals, at other times and in other places, to other civilizations that ran a similar course in India, China, Mexico, Greece, and Rome.

The little, almost self-contained groups within this stock travelled farther and farther afield from their original home. Hemmed in on the south by slowly extending deserts they moved in the wake of the temperate woodlands. Along rivers and other less open corridors they percolated even into the heart of the forests. With their sharp stone axes they felled trees

and made clearings where the gentle summer rains kept the herbage fresh and the grasses green, thus providing rich pasturage for the sheep and cattle, and by swelling the grain in the ear brought richer harvests.

Thus it came to pass that in about a thousand years, during which Egypt and Mesopotamia were climbing to their prime, these Neolithic farmers entered Western Europe and brought the benefits of their new way of life to the Mesolithic peoples whose long and courageous struggle was then ended. These were themselves absorbed and contributed another element to this evolving stock.

The Neolithic communities were by no means completely isolated; they were knots in a living network whose threads consisted of traders, merchants, adventurers, seeking strange luxuries – amber, jet, gold for the cities from whence they came – and exchanging the surplus products of their home land, 'goodly Babylonish garments' and the like. As written history shows the cities perished and their civilizations declined, but the nexus knitted in Neolithic times went on evolving.

This evolutionary process is reflected in the scenery around us. To the wonder and complexity of this, man is still making his contribution, which is now so marked that it has become the custom to speak of it as the cultural landscape as opposed to the natural landscape. Where man cooperates with Nature the result is satisfying. Where he is making a mess Nature will return quietly and hide it as a book of remembrance under her garment of beauty.

Whither is all this tending? That is another mystery crowning those already mentioned. One of endless new arrangements and rearrangements of electrons, atoms, and molecules; of cells, tissues, and organs. The mystery of new properties emerging with each new arrangement; life, consciousness, and self-consciousness; mind, will, and love. These are but beams of the profoundest mystery that underlies and envelopes all things seen and felt, things that are the objects of scientific study and enquiry. The end cannot be imagined, but so long as Nature continues to hold her child upon her knee he may go forward with hope and confidence.

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THE FACE OF THE SUN

H. W. Newton

A 422

A special job of astronomers during the International Geophysical Year, when this book first appears, is the study of the surface of the sun. The tools which modern technical skill has newly placed at their service, among them radio telescopes such as that at Jodrell Bank, are adding almost daily to our knowledge of the constitution and the activity of the one star we can observe at what, in terms of stellar distances, may be called 'close range'.

Here is the story of what men have learnt about the sun during the three and a half centuries since Galileo's early telescope first disclosed the existence of sunspots. The fifty-thousand-mile-long tongues of gas which shoot out from the sun's surface into space, the streams of solar particles which enter earth's atmosphere to cause magnetic storms that disturb our radios, and to paint the night sky with displays of the Aurora Borealis, the obscure effects of solar activity on our weather conditions are described, discussed, and so far as is yet possible explained.

And – because our sun, we may suppose, is in many ways typical of many of the countless stars of remotest space – we are given in these pages a glimpse of happenings far beyond our own system, in similar stars at the remotest bounds of the universe.

PENGUIN BOOKS

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H. H. Swinnerton was born in 1875 the son of an itinerant Methodist minister whose triennial removals resulted in an early life spent in out of the way country places, mainly in the Yorkshire Dales.

In 1898 he passed the London University Degree examination in Geology, Botany, and Zoology gaining the highest place in First Class Honours and later the Degree of D.Sc. in Zoology. After three years' zoological research at the Royal College of Science he entered the University College of Nottingham as Lecturer and Demonstrator in those three sciences. During the next few years he applied his training in Zoology to the study of fossils and in 1912 was appointed to the Chair of Geology and Geography. In 1938 he was elected President of the Geological Society of London and four years later was awarded the Murchison Medal by the Council of the Society.

He has published many papers in scientific journals on Palaeontology, Archaeology, and Geography, and has written a number of books including *The Outlines of Palaeontology*. For some years he was Vice-Principal of the Nottingham College. From 1939 onwards he was Chairman of the University Joint Recruiting Board. In 1950 he was decorated Commander of the British Empire, Civil Division. He now occupies his time in writing, gardening, playing with fossils, and painting in water colours.

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